TRANSACTIONS
OF THE

INSTITUTION
OF
NAVAL ARCHITECTS.

1867.

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OF THE

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VOLUME VIII.

1867.

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OBJECTS OF THE INSTITUTION.

The objects of the Institution of Naval Architects—which was established to promote the Improvement of Ships, and of all that specially appertains to them—are comprised under three heads :—

First, the bringing together of those results of experience which so many shipbuilders, marine engineers, naval officers, yachtsmen, and others acquire, independently of each other, in various parts of the country, and which, though almost valueless when unconnected, doubtless tend much to improve our navies when brought together in the printed Transactions of an Institution.

Secondly, the carrying out, by the collective agency of the Institution, of such experimental and other inquiries as may be deemed essential to the promotion of the science and art of shipbuilding, but are of too great magnitude for private persons to undertake individually.

Thirdly, the examination of new inventions, and the investigation of those professional questions which often arise, and were left undecided before the establishment of this Institution, because no public body to which professional reference could be made, then existed.

BYE-LAWS AND REGULATIONS.

CONSTITUTION.

1. The Institution of Naval Architects shall consist of four classes, *viz.*, Members, Associates, Honorary Members, and Honorary Associates.

2. *Members.*—The Class of Members shall consist exclusively of Naval Architects.

3. *Associates.*—The Class of Associates shall consist of persons who are qualified, either by profession or occupation, or by scientific or other attainments, to discuss with Naval Architects the qualities of a ship, or the construction, manufacture, or arrangement of some part or parts of a ship or her equipment.

4. *Honorary Members.*—The Class of Honorary Members shall consist of persons who are eligible as Members, and upon whom the Council may see fit to confer an honorary distinction.

5. *Honorary Associates.*—The Class of Honorary Associates shall consist of persons who have contributed to the improvement of ships or their equipment, and upon whom the Council may see fit to confer an honorary distinction.

ELECTION AND DUTIES OF OFFICERS.

6. The Officers of the Institution shall consist of a President, Vice-Presidents, Members of Council, Associate Members of Council (not exceeding in number one-third the number of Members of Council), a Treasurer, two Auditors of Accounts, and a Secretary or Secretaries.

7. A General Meeting of the Members and Associates of the Institution shall be held annually; and at this Annual General Meeting the Members of Council, Associate Members of Council, Treasurer, and Auditors for the ensuing year shall be elected.

8. At the Annual General Meeting Members only shall vote in the Election of Members of Council, and both Associates and Members in the Election of Associate Members of Council, the Treasurer and the Auditors.

9. As soon as may be convenient after the Annual General Meeting, the newly-elected Members and Associate Members of Council shall meet and elect the President and Vice-Presidents for the year, Members and Associate Members of Council both voting.

10. *President.*—Both Members and Associates of the Institution shall be eligible for election as President. The President shall preside over all Meetings of the Institution, and of Officers of the Institution, at which he is present, and shall regulate and keep order in the proceedings.

11. *Vice-Presidents.*—Both Members and Associates of the Institution shall be eligible for election as Vice-Presidents. In the absence of the President, one of the Vice-Presidents shall preside at the General Meetings of the Institution, and shall regulate and keep order in the proceedings.

12. In case of the absence of the President and of all the Vice-Presidents, the Meeting may elect any Member of Council or Associate Member of Council, and in case of their absence any Member present, to preside.

13. The Chairman at any Meeting of the Council or of the Institution, when the votes of the Meeting, including his own, are equally divided, shall be entitled to give a casting vote.

14. Persons holding the office of Vice-President shall at all times be entitled to sit and vote with the Council.

15. *Past Presidents and Vice-Presidents.*—All Members who have held the posts of President and Vice-President shall, while their connection with the Institution as Members lasts, be entitled to sit and vote with the Members of Council.

16. *Members of Council.*—Members only shall be eligible for Election as Members of Council at the Annual General Meeting.

17. *Associate Members of Council.*—Associates only shall be eligible for Election as Associate Members of Council at the Annual General Meeting.

18. The Direction and Management of the Institution shall be vested in the Council for the time being, the Associate Members voting with the Members of Council in all cases, except in the decision of questions directly affecting the forms of ships and the construction of their hulls.

19. The Council shall meet as often as the business of the Institution requires, and at every Meeting five "Members of Council" shall form a *quorum*.

20. The Council may appoint Committees to report to them upon special subjects.

21. All questions shall be decided in the Council by vote; but at the desire, expressed in writing, of any four Members or Associate Members present, the determination of any subject shall be postponed to the succeeding Meeting of the Council.

22. An annual statement of the funds of the Institution, and of the receipts and payments of the past year, shall be made under the direction of the Council, and after having been verified and signed by the Auditors, shall be laid before the Annual General Meeting.

23. The Council shall draw up an Annual Report on the state of the Institution, which shall be read at the Annual General Meeting.

24. It shall be the duty of the Council to adopt every possible means of advancing the Institution, to provide

for properly conducting its business in all cases of emergency, such as the death or resignation of Officers, and to arrange for the publication of the Papers read at the Meetings, or of such documents as may be calculated to advance the objects of the Institution.

25. *Treasurer.*—Only Bankers, or Members of Council, or persons who have been Members of Council, and are still Members of the Institution, shall be eligible for election as Treasurer.

26. *Auditors.*—All Members and Associates of the Institution shall be eligible for election as Auditors.

27. The Auditors shall have access at all reasonable times to the Accounts of the pecuniary transactions of the Institution; and they shall examine and sign the annual statement of the Accounts before it is submitted by the Council to the Annual General Meeting.

28. *Secretary.*—The Secretary or Secretaries shall be elected by the Council, and shall be removable at the will of the Council, after due notice given. The salary of the Secretary or Secretaries shall be fixed by the Council.

29. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all Meetings of the Institution and of the Council; to take Minutes of the proceedings of such Meetings; to read the Minutes of the preceding Meeting; to announce donations made to the Institution; to superintend the publication of such Papers as the Council may direct; to have charge of the library, museum, and offices of the Institution; and to direct the collection of subscriptions and the preparation of accounts. He shall also engage, and be responsible for, all persons employed under him, and generally conduct the ordinary business of the Institution.

DESIGNATION OF MEMBERS AND ASSOCIATES.

30. Any Member, Associate, Honorary Member, or Honorary Associate, having occasion to designate himself as belonging to the Institution, shall state the class to which he belongs according to the following abbreviated forms, *viz.:* M.I.N.A.; Assoc. I.N.A.; Hon. Mem. I.N.A.; Hon. Assoc. I.N.A.

ELECTION OF MEMBERS AND ASSOCIATES.

31. *Admission of Members.*—Every Candidate for admission into the Class of Members, or for transfer into that Class from the Class of Associates, shall be more than twenty-five years of age, and shall comply with the following regulation:—

He shall submit to the Council a statement, showing that he has been professionally engaged in shipbuilding for at least seven years in some public or private shipbuilding establishment, and setting forth the grounds upon which he bases his claims to be considered a professional Naval Architect, and to be admitted as such to the Membership of the Institution. This shall be signed by at least three Members, whose signatures shall certify their personal knowledge of the Candidate, and approval of his statement; or, in the case of persons not British born, the signatures of three Members shall be required, in confirmation of their personal knowledge of the Candidate's scientific reputation.

32. These preliminary conditions being satisfied, the Council shall then consider whether the practical experience and professional attainments of the Candidate are such as entitle him to be brought forward by the Council as a Naval Architect. If four-fifths at least of the received votes of the professional Members of the Council are in favour of his application, and such four-fifths constitute a majority of the professional Members of the Council, his proposal for admission shall be submitted to the Members of the Institution (who shall have access to the applicant's statement) at an Ordinary Meeting of the Institution, for them to vote upon, by ballot.

33. *Admission of Associates.*—Candidates for Associateship shall submit to the Council a proposal for their admission, setting forth therein a statement of their claims to be admitted as Associates. Their proposal, if approved by the Council, shall be submitted by them at an Ordinary Meeting of the Institution, for the Members and Associates jointly to vote upon by ballot.

34. The proportion of votes for deciding the election of Members and Associates shall be at least four-fifths of the numbers recorded.

SUBSCRIPTIONS.

35. Each Member and Associate shall pay an Annual Subscription of two guineas in advance; the first Subscription being payable on his election, and all future ones on the 1st day of January of each year. Any Member or Associate withdrawing from the Institution after that date is still liable for the amount of Subscription due on that day.

36. Any Member or Associate may compound for his Annual Subscription, for life, by a single payment of not less than thirty guineas.

MEETINGS.

37. Meetings for the Reading of Papers shall be held as frequently, and at such times, as the Council may determine.

TRANSACTIONS.

38. The Transactions of the Institution, including the Papers read at the Ordinary Meetings, and Reports of the Discussions by which they are followed, shall be edited by the Secretary, and printed under the direction of the Council.

39. The Transactions shall not be sold, or supplied for sale, by the Institution; but a copy shall be sent free to each Member and Associate.

40. Members and Associates are particularly requested to communicate to the Secretary any change of address.

INTRODUCTORY PROCEEDINGS.

THE Annual Meetings were held in the Hall of the Society of Arts, John Street, Adelphi, on Thursday, Friday, and Saturday, April 11th, 12th, and 13th.

The Opening Meeting was held on Thursday, at 12 o'Clock, and was presided over by the Right Hon. Sir John S. Pakington, Bart., M.P., G.C.B, D.C.L., and President of the Institution.

Mr. MERRIFIELD (Hon. Sec.) read the Report of the Council:—

REPORT OF COUNCIL, APRIL 11th, 1867.

"The Council have great pleasure in congratulating the Institution on the useful work which it has done, during the past and previous years.

"The Volume of the *Transactions*, which has just been published, contains, in addition to the usual store of valuable Papers and Discussions, a very complete Index to the whole of the seven Volumes already published. It is proposed, in future, to index every Volume as it appears, and to consolidate these indices at periodical intervals.

"The financial position of the Institution is not so flourishing as might be desired, and has occupied the attention of the Council. Measures have been taken which, it is expected, will increase its income on the one hand, and, on the other, diminish its expenditure. The number of Members and Associates has slightly increased this year over last year.

"The Council have received an intimation that the Institution cannot continue to occupy its present Offices at 7, Adelphi Terrace, after the 24th of June next, except at a largely increased rent. The Council have decided to accept the notice to quit.* They propose to make application to Her Majesty's Government to grant them rooms either in Somerset House, or elsewhere, and they hope that in this way a very large item of their expenditure, the rent of the Offices, will be economised.

"The Council have appointed Mr. C. W. Merrifield, who has for some time acted as Secretary at the Meetings, and has edited the recent Volumes of the *Transactions*, as Honorary Secretary to the Institution. They have also appointed an Executive Committee, consisting of Mr. Scott Russell, Mr. Reed and Mr. Ritchie, to assist the Honorary Secretary in the discharge of his duties.

"The time of the Council has been seriously occupied during the past year with the subject of the 'Safety of Iron Ships,' suggested by the Right Hon. President, and recommended by the Meeting last year to their consideration. They have met a great many times to consider what steps could be usefully taken on behalf of the Institution, in order to prevent some portion of the disastrous loss of life and property annually incurred at sea. Their recommendations are embodied in a Report which will be read to you.

"The School of Naval Architecture and Marine Engineering at South Kensington is still watched with great solicitude by the Council. They are happy to say that it progresses favourably, and that the

* By a subsequent arrangement, the same Offices are retained until Lady-day, 1868, at least.

number of Scholars increases annually. Several of the Scholars are on the point of completing their third session of instruction in the School, and the final Examinations, for the first time, begin on Easter Monday next. These Examinations, and the diplomas depending upon them, are not confined to Students of the School, but are open to all *bonâ fide* members of the two professions of Naval Architects and Marine Engineers, and the Council are glad to be able to state that several gentlemen have applied for admission to the Examinations accordingly."

Institution of Naval Architects.

Balance Sheet as at 31st December, 1866.

Dr.		£	s.	d.	Cr.	£	s.	d.
1865.					1866.			
Dec. 31	To Balance	594	19	9	Dec. 31. By Cash paid—			
1866.					„ Printing and Binding *Transactions*, Vol. V., separate copies of Papers, &c.	346	13	0
Dec. 31.	„ Cash received—				To Account Printing Vol. VI. ... 75 0 0			
	Subscriptions	815	12	6	„ Copper Plate Engraving for Vol. VI. 111 5 3			
	Proceeds of Sale of Volumes to New Members and Associates	60	18	0		186	5	3
					„ Reducing Drawings for Vol. VII.	27	16	0
					„ Sundry Printing, Session 1866 ...	29	3	4
					„ Reporting, Session 1866 21 6 0			
					„ Ditto sundry 4 8 8			
						25	14	8
					„ Refreshment and Attendance at General Meeting, 1866	9	6	0
					„ Furniture and Repairs	29	11	0
					„ Bookbinding, &c., on a/c. Library	17	8	10
					„ Rent of Rooms for year to 29 Sept., 1866	112	10	0
					„ Cleaning ditto, 31 December	13	0	0
					„ Paid by Executive Committee on Secretarial Account, 1864-5-6 ...	200	0	0
					„ Salary to Assistant Secretary for year to 21st December, 1866 ...	150	0	0
					„ Ditto to Clerk for year to 29 Dec., 1866	57	0	0
					„ Postages	29	16	8
					„ Ditto and other Charges on account of Distribution of Volumes	22	2	6
					„ Disbursements	47	5	3
					By Balance in Treasurer's hands 136 9 6			
					„ Ditto, Assistant Secretary's 31 8 3			
						167	17	9
		£1,471	10	3		£1,471	10	3

1866.				
Dec. 31.	To Balance in Treasurer's hands	136	9	6
	„ Ditto in Assistant-Secretary's hands	31	8	3
		167	17	9

E. E.
March 27, 1867.

(Signed) JOHN GRANTHAM, NATHL. BARNABY, *Auditors.*
J. D'A. SAMUDA, *Treasurer.*
CHAS. CAMPBELL, *Assistant-Secretary.*

The PRESIDENT: Gentlemen, I cannot open this Session of this admirable Institution for the year 1867, having the honour of being your President, without expressing the great and sincere satisfaction which it gives me to meet you again, and also the satisfaction with which I see upon this occasion, as I have upon many former occasions, a very large and numerous attendance of those able and scientific men who take an interest in the prosperity and the progress of this Institution. But, Gentlemen, there is one serious drawback to the pleasure which I feel in again filling this chair, and that is, that whilst on former occasions I have always been obliged to offer to you some apology, or to request your indulgence, on account of the extent to which, from Parliamentary duties, I was obliged to absent myself from the Meetings of this Society, on the present occasion, from the heavy official duties in which I am engaged, (cheers), I am sorry to say I must trust to your kindness and indulgence to allow me, I am afraid, to be absent from the greater part of your proceedings. Indeed, Gentlemen, I am so situated this morning, that I am now interfering with the prescribed order of our proceedings. You will see in the programme of proceedings that the next item of business after the Report of the Council, which you have just heard, is that the Special Report of the Council on the Safety of Iron Ships ought now to be read to you; but really my time is so limited that I am obliged, I am sorry to say, to request your permission so soon to retire from the room, that I beg to take the liberty of offering to you the few observations which I desire to make, before that Report of the Council is read.

Gentlemen, with regard to the contents of the General Report which you have just heard read, I am happy to say that now, as on previous occasions, I can only address you in that language of congratulation which the Council have adopted with regard to the continued prosperous and successful action, and, I think I may say, the general prosperity of this Institution. There is, I regret to add, a paragraph in this Report adverting in somewhat unfavourable terms to the financial position of the Institution; but I am happy to add that this has become the subject of conversation this morning at a Preliminary Meeting of the Council, and I am happy also to say, that although the state of our finances is not so prosperous as the friends of the Institution could desire, still there is nothing at all to forbid the confident hope that financial prosperity may be entirely restored, and that no impediment of that sort may for the future impede or affect the useful action of this Society. Those who are Members of the Institution have probably received the Seventh Volume of the *Transactions*, which has been recently published, and therefore it is hardly necessary for me to advert to the valuable nature of that volume, and especially to the fact that it contains a very complete index of all our former *Transactions*, and I probably should not have thought it worth while to occupy time by any reference to the new volume, were it not for the acknowledgment which I think is due from every Member and every friend of this Institution for the great ability and the laborious zeal with which our Secretary, Mr. Merrifield, has prepared that Index which we find so useful (cheers).

Gentlemen, there is another topic touched upon in this Report which is of immediate importance at all events to the comfort and the means of action of this Society. I allude to the fact that we are likely very soon to be obliged to leave the offices in Adelphi Terrace, which have been so long occupied by the Institution, and partly with the view to perhaps increased accommodation, and partly with the view, it must be acknowledged, to financial considerations, it has become a question with the Council whether or not this valuable Institution, which is acquiring year by year greater national importance, has not a fair claim to receive from the Government accommodation in some of the Government establishments (cheers). This suggestion has been offered by the Council, and I felt it

my duty, in consequence of that suggestion, to communicate with the Duke of Marlborough, as Lord President of the Council, to ask his Grace whether in his opinion there were any apartments in any of the Government establishments, which could, as a temporary arrangement at all events, be occupied by this Society. I am very sorry to say I have received from his Grace an unfavourable answer. He has taken our application into full and friendly consideration, and I have received from him a letter to say, that, neither at South Kensington (and perhaps, it would be somewhat doubtful whether, even if we could get permission to go to South Kensington, it would be a convenient situation, considering the distance) nor elsewhere, can we be accommodated. It, therefore, will be necessary, from the expiration of our term in Adelphi Terrace, which will take place in two or three months from this time, that we should look out for apartments elsewhere. It has been suggested to me that, perhaps, at Somerset House, under some new arrangement hereafter, accommodation might be given to us. At all events, at present Somerset House is fully occupied, and I believe there is no chance of our receiving accommodation there within any early period. Therefore I would suggest to the meeting, and I think it is a question for the consideration of the Council, whether or not it may not be, at least, worth while—I speak now with perfect freedom from any connexion with the Admiralty (hear hear)—but I would throw out whether it might not be worth while, considering the important national objects that are carried out by this Institution, to make an application to the Admiralty, and whether or not we might not be considered entitled to an annual grant to assist us in the national objects which we carry out. It must be well known to those whom I am now addressing, that, in the case of the United Service Institution—no doubt a most valuable Institution—both from the War Department and the Admiralty pecuniary assistance is given to carry out the affairs of that Institution. Of course this Institution could establish no claim to assistance from the War Department; but I think we might establish a claim, which, so far as our finances are not prosperous, might be considered as unanswerable, to have assistance from the Board of Admiralty. At all events I think it would be worth while for the Council, under the circumstances I have adverted to, to make an application of the character to which I have alluded.

Gentlemen, I will now advert for a moment to that which certainly has been by far the most important action of this Institution during the year that has elapsed since I had last the honour of meeting you in this chair. It must be, I think, in your recollection, that at the time when we met last year, which was somewhat earlier than it is now, the minds of the public were painfully occupied by the dreadful catastrophe which had just occurred in the Bay of Biscay, in the loss of the *London* passenger ship. It may be in your recollection that I thought it my duty, in the Opening Address which I delivered at our last Annual Meeting, to call the attention of this Society to that dreadful event, and to point out to them the opinion that I ventured to entertain, that it would be hardly possible for the able and scientific Members of this Institution to address themselves to any question more appropriate to the objects for which we have been called into existence, than to enquire whether or not that dreadful catastrophe, accompanied, as it was, by not a few similar accidents about the same time, was or was not to be traced to any defect, either in the architectural skill with which our passenger ships are constructed, or to any defect in our laws with regard to the protection of that most important, but quite helpless, portion of our fellow-subjects, who are called upon and compelled by their duties and vocations in life to cross the seas, and to become passengers in those ships. The suggestion which I ventured to offer was warmly responded to by the Meeting which I had the honour to address, and before the close of our proceedings a motion was made—I

think by my friend, Mr. Reed, and seconded by Mr. Scott Russell—that the Council should devote their serious attention to the question which I had taken the liberty of suggesting. I am happy to inform you, Gentlemen, that that part of our proceedings last year has been most satisfactory in its result, and most honourable to the Members of this Institution. The Council undertook what certainly has proved a very laborious and a very arduous duty. They commenced their proceedings, if I remember rightly, about the month of May. My many avocations rendered it impossible for me to do that which I would gladly, though perhaps uselessly, have done, namely, attend those meetings; therefore I am the more free to speak of the view I entertain of the manner in which those proceedings were conducted. Under the able presidency of our distinguished friend, Sir Edward Belcher, the Council met on no less than fourteen different occasions, and in the course of those fourteen sittings, they entered in the most close and able and satisfactory manner into the interesting question which had been referred to them. Their report was drawn up towards the close of the last year. That report, as I have already stated, if it had not been for the unfortunate pressure on my own time, would already have been read to you. But, Gentlemen, it will be read to you as the next proceeding in the business of this morning, and I am confident it must impress the mind of every one who hears it with a deep sense of the great ability and great zeal with which that enquiry has been conducted. I hope and believe that the Institution will attach very great importance to the series of, I think, fifteen suggestions, which that report embodies. I think also that I ought to add, that it is I believe the unanimous feeling of the Council, that in addition to the suggestions which they have embodied in their report, and which of course from the nature of this Institution, relate mainly, if not solely, to the question of the construction of our ships, but I believe I may say it is their unanimous opinion that it would be very desirable that the many remaining questions of a different nature, as affecting our laws for the protection of passengers, should become the subject of enquiry by a Royal Commission (hear, hear). With this view, a deputation from the Council did me the honour to request an interview with me upon the subject of their report. That interview took place only a few days ago. At my request the Duke of Richmond, as President of the Board of Trade, did us the favour to join me in receiving that deputation. A more interesting deputation I think I never listened to. It was composed of men most eminent for their acquirements on this subject. The Duke of Richmond was deeply struck with the whole of our conversation. What may be the ultimate decision of the Government I am at present unable to say; but certainly the question will be taken into consideration by the Government, whether or not the state of our laws upon this interesting subject are not so far unsatisfactory and incomplete as to make it desirable that the enquiry by a Royal Commission should be added to that enquiry by the Council of this Institution which has been already so ably and so completely conducted (cheers).

I do not think I need detain you by making any further remarks upon this subject, important as it is. But, Gentlemen, there is another subject, by no means a new one, but which is still of the greatest importance; and I will advert to it for a moment, mainly because I am happy to say I can do so with terms of increasing satisfaction. I allude to the continued and successful progress of that School of Naval Architecture, the existence of which is mainly to be attributed to the persevering and zealous exertions of this Institution (cheers). I am happy to say that every report which I hear of the progress of that School of Naval Architecture is satisfactory, with this single exception, that I wish I could hear of a larger proportion of private pupils connected with our own country. At present a very considerable majority of the pupils in the School of Naval Architecture are those supplied by the Admiralty, and I am informed that many of the number of those that come under the definition of private pupils are foreigners. I think

it is a matter of pride and satisfactory reflection that our school should already have attracted so much notice, and inspired so much confidence that foreigners find it worth their while to come to England to study in that school; and I have no doubt, from the number of Government pupils, great impulse has been given to the study of this most important science of naval architecture, and we shall find among the private pupils there will be no inconsiderable supply of competent men added to this profession. But I confess I should be glad to hear, in the first place, that the number of private pupils was increased, and, secondly, that the preparation of those private pupils in the study of mathematics was somewhat more satisfactory upon the commencement of their career in the School of Naval Architecture than I am led to suppose at present it is.

Years have passed away, and a great revolution in the construction of our ships has taken place. Amongst the various questions still remaining, the only one I think I can now speak of as one of very pressing interest, is that question which still certainly remains an unsettled question—I mean the question between the turret system and the broadside system. When I have had the pleasure of addressing you on former occasions, I have thought it my duty, more or less, to touch on this question, and I did so last year; but I think I may now speak of that question as being so far in a satisfactory state, that it is in a fair way to practical solution. On former occasions I have felt it my duty to express my regret that the Board of Admiralty—of course speaking here, as I am sure you will fully believe, with no party feeling, and in no party sense (hear, hear)—but I have felt it my duty, in the public interest, to express my regret that, for a considerable period, the late Board of Admiralty, whilst recognising the importance of the suggestion of the turret, had not taken any adequate steps to carry that question to the state of practical experiment. No further complaints of this kind can exist. The late Board of Admiralty (and I entirely give the credit to the late Board of Admiralty)—not so soon as we might have wished—but they eventually did take those steps which I think the public interest and the public voice required, and lately they decided on the commencement of two ships which involved this experiment to its fullest extent, and by which I hope this great experiment and problem will be fairly solved. I allude to the *Monarch*, which I think was designed by my friend Mr. Reed, and the *Captain*, with respect to which ship Captain Coles received from the late Board, and still more from the present Board (for the matter was not quite settled when the late Board went out) *carte blanche* to construct that ship according to his own views of what his own system ought to be. So that I am happy to say, as far as regards those two ships, that great and important question which has so far divided the nautical world is in course of fair solution, and we must await the trial of those experiments upon a question, which, I cannot conclude my remarks without adding, is a question open to very serious doubt.

Gentlemen, I do not remember at this moment any further questions upon which I should desire to touch. I think I may say, echoing I believe the opinion of one of our most important Members, that if this Institution of Naval Architects were now to vanish from the scene, and this were to be, which I hope is very far from being the case, our last assembly, I think those Gentlemen who promoted the establishment of this Institution might well reflect with pride upon the course they took, and with a conviction that this Institution had conferred great public benefits if it were only in the recollection of the two subjects to which I have adverted to-day—first, the establishment of the School of Naval Architecture; and, secondly, that enquiry, which has been conducted with so much ability and so much zeal throughout the past year, into the construction of those ships which convey our countrymen by sea. Those are the two great subjects. I think I may say those are two great acts, and I cannot close my reference to the last of them, namely, the

enquiry into the construction and safety of iron mercantile ships, without expressing—and I hope in so doing I am expressing the sense of every one that hears me—my warm acknowledgment and hearty gratitude to the able Gentlemen who have so well conducted the enquiry.

With regard to the future action of the society, so far from any idea of its vanishing from the scene, I confess I, in a sanguine spirit, anticipate for it a career of continual prosperity. Fresh arrangements have lately been made, and they are of the most promising nature. I am very happy indeed to be able to say that notwithstanding his official avocations and exertions, and the great calls upon his time, which of course must be the consequence of his position, Mr. Reed has again joined the active Members of this society (great cheering). We are now in the position of having an executive committee consisting of three Gentlemen whose competence will be universally acknowledged, namely, Mr. Scott Russell, Mr. Reed, and Mr. Ritchie; and to the very great advantage of this society, and in a manner which demands our warmest acknowledgment, I am happy to say that Mr. Merrifield has given gratuitously his services as the honorary secretary of this Institution. Aided as they are by the zealous assistance of Mr. Campbell, I think I am justified in the hope, with the expression of which hope I will conclude these observations, that through many future years we may look forward to a constant increase of prosperous and successful action, and that year by year this Institution will be more and more recognised as conferring great and important advantages on the country (loud cheers).

The PRESIDENT: Gentlemen, I am sorry that, in consequence of an unforeseen engagement, I am now obliged to ask you to be kind enough to release me. I am very sorry that I cannot stay any longer. Perhaps Mr. Lloyd, one of the Vice-Presidents, will take the Chair. I hope you will make allowance for my position, which obliges me to leave you (cheers).

The Right Hon. Baronet then vacated the Chair, which was taken, as proposed, by Mr. Lloyd.

Mr. MERRIFIELD (Hon. Sec.) then read the following:—

GENERAL REPORT,

Based upon the Resolutions passed by the Council relating to the Safety of Iron Ships.

The President of the Institution of Naval Architects, in the opening address of the Session of 1866, said with reference to the then recent loss of the *London* iron passenger steamer, in the Bay of Biscay, "The circumstances of the sad event of the loss of the "*London*, accompanied as it was by the simultaneous loss of another ship of still larger "size, and of a higher reputed character," (the *Amalia*) "was, I think, an event so "remarkable, that I should be very sorry indeed if this Annual Meeting of this "Institution were to pass by without some notice being taken of the extraordinary "circumstances of the loss of that ship, and without some discussion upon what we "suppose to be the causes of the loss, and the faults if any of the construction of those "ships." * * * "Regulations must be made; ships must be built for the convenience of "passengers; but they must not afterwards be unduly loaded with cargo, so as to be

" unsafe upon the sea. The passengers who pass to and fro are not judges of the " question; they can take no precaution for their own safety; it is to the skill and " science of those who build these ships that the passenger trusts, and to the care which " the Legislature and the Government are bound to take of their fellow-subjects. Under " these circumstances, I do sincerely trust there will be a discussion upon this question."

At the close of the meetings the following Resolution was adopted unanimously:—

" That in the opinion of the Members and Associates of this Institution, it is desirable that an " early meeting of the Council take place, for the purpose of considering, with reference to the " President's Opening Speech, and the Papers that have been read on the security of iron ships, " what recommendations could best be offered to the public, in order to prevent as far as possible " the loss of passenger and other vessels."

In accordance with this Resolution, the Council have given careful consideration to the question of the safety of iron ships, all the Members of the Council having been consulted at each stage of the proceedings. The Council have ultimately arrived at the following conclusions, and offer them, with such recommendations as they contain, to the profession, in the hope that they may be adopted by shipowners and builders, and may tend to increase the safety of passenger and other vessels.

Dimensions.—1. No general rule can be safely laid down for regulating the proportions of length and depth to the breadth of a ship, and a great variety of proportions of length and depth to breadth may be safely adopted, and the ship made sound and seaworthy, by judicious form, construction, and lading.

Information on Ships' Papers.—2. The construction load-water-line of every ship, and her scale of displacement from light to load-water-line, should be appended to every design of a ship, shewing the extreme draught to which she should be laden; and measures should be taken to ensure that this information be recorded on the ship's papers. It is desirable also that, along with a ship's papers, in the possession of the captain, there should always be carried a scale of displacement, a sail draft, and a set of outline plans of the ship, comprising a longitudinal section, and at least four cross sections of the ship. On these plans should be marked the capacity, in tons of 40 cubic feet, of each compartment of the hold. The surplus buoyancy of each compartment up to the load-water-line, or its power to carry dead weight, should be given in tons dead weight. These papers should always accompany the ship's register, and a copy of them should be lodged in the Custom House of the port, from which the ship hails.

Freeboard.—3. There is a minimum height of freeboard which cannot be safely reduced in sea-going ships of ordinary fitment; and it is desirable to fix this minimum

height. Freeboard should be understood to be the vertical height of the upper surface of the upper deck (not spar-deck) at the side, amidships, above the load-water-line. The proportion of freeboard should increase with the length. One-eighth of the beam is a minimum freeboard for ordinary sea-going ships of not more than five breadths to the length, and $\frac{1}{32}$ of the beam should further be added to the freeboard for each additional breadth in the length of the ship: this would give:—

For a ship of 32 feet beam and 160 feet long, 4 feet freeboard.
For a length of 192 feet, 5 feet freeboard.
For a length of 224 feet, 6 feet freeboard.
For a length of 256 feet, 7 feet freeboard, the beam remaining the same; but as the addition of a spar-deck on long vessels may be considered an equivalent or substitute for the increased freeboard required for extra length, a complete spar-deck would leave the freeboard of these extra lengths at the original height of 4 feet.

Poops and Forecastles.—4. It is not considered desirable to offer any recommendations with regard to poops and forecastles. It must depend entirely upon the professional judgment of the designer of a ship, whether, looking to her proportions, form, and purpose, the additions of poop and forecastle are expedient and safe. In general, where poops and forecastles are adopted, they should be closed and seaworthy, but their weight may be inexpedient in long fine ships; and there are cases where a light top-gallant forecastle (*i. e.*, an open forecastle raised above the level of the upper deck) may be useful in keeping heavy seas out of the ship. In general, spar-decks in long ships are preferable to poop and forecastle, and no diminution of freeboard should be allowed for a poop or forecastle.

Compartments.—5. It would add much to the strength and security of steamships if transverse and longitudinal bulkheads, coal bunkers, iron lower decks, and screw alley were all so connected with the hull of the ship and with each other, as to form independent cellular compartments, water-tight, and having all their communications with the decks and each other by water-tight doors worked from the deck. In proportioning the compartments of a ship (and especially of ships devoted to passengers) it is very desirable so to arrange them that if any *two* adjacent compartments be filled, or placed in free communication with the sea, the remaining compartments will float the ship. It is considered that no iron passenger ship is well constructed unless her compartments be so proportioned that she would float safely were any *one* of them to fill with water, or be placed in free communication with the sea. Double bottoms are to be regarded as a great element, both of safety and strength, in the structure of a large iron ship.

Ventilation.—6. It is very desirable that sufficient ventilation should always be provided in passenger ships to admit of closing all side scuttles and battening down, or otherwise enclosing, all hatches in bad weather.

Hatchways.—7. In regard to hatchways and openings in the deck, no limits can be set to their size; but it is desirable to carry the beams of the ship across them without interruption wherever practicable:—the beams may also be made removable where required, being replaced on going to sea. All coamings over engine and boiler rooms in passenger ships should be as high as practicable, of iron, and riveted to the beams and carlings. Openings in the deck may be fitted with solid coverings, hinged in place so as to be readily closed.

Side Scuttles and Stern Windows.—8. It being considered that all openings in the sides or ends of vessels are subject to accidents that endanger the safety of ships, it is desirable that the side and stern windows should, in addition to the glass lights, have *hinged dead lights*, with a view to their being always in place; and that all cargo ports should be strongly secured by iron cross bars.

Openings to the Sea.—9. It is believed that all openings from and communications with the sea from engine room and pipes should be protected by conical, or Kingston, or sluice valves, and similar precautions should be taken for all openings through the bottom of the ship, where damage to pipes or ship would admit water into the holds.

Pumps.—10. It is considered that all steam vessels, if of iron, should have a brass barrelled hand-pump to every compartment except the forward and after ones—the former to have a sluice cock; or that, as a substitute for these pumps, there should be patent pumps having independent connections to this extent. They should also have a donkey engine and pump capable of pumping from the bilge and from the sea, of feeding the boilers, and of throwing water on deck. All vessels should have one or more bilge-pumps, worked by the large engines, with bilge injection pipes if the engines have condensers. In large vessels the donkey engines should have a separate boiler high above the water-line, and also communication with the main boilers. All vessels should have a set of bilge pipes connecting every hold and the engine compartments with these pumps. As a security against fire, there should be pumps on the upper deck, fitted as force pumps, and provided with a sufficient length of hose (with the necessary copper delivery jets) to reach either extremity of the vessel, and also provided with suction hose or pipes from the sea. The cocks, by which the working of the pumps is regulated, should be carefully arranged and marked, and great care should be taken that both cocks and pipes are accessible. A plan of the whole should accompany the ship's papers, and the crew should be periodically exercised in their use.

Stowage.—11. The stowage of a ship, whether done by contract or not, should be done under inspection of the captain of the ship, and should be conducted under his own orders only; and he alone should be held responsible for the good stowage of his ship. Ships are often very badly stowed, the weights being sometimes too low, thus causing them to roll with such rapid and violent motions as to carry away the spars, and otherwise endanger the safety of the ship, and at other times too high, thus making the ships crank, and liable to turn over. A ship may, however, generally, whatever her form, be so stowed as to avoid both dangers. As the character of the ship in these respects varies, so does the number of oscillations she would make per minute, if she were set rolling in still water, by men running across her deck, or other means, and then allowed to come to rest; that is—if the ship be crank, the number of oscillations per minute will be few, and if she be too stiff they will be numerous; but under the same conditions of stowage, the number will always be very nearly the same, whatever the amount of the impulse to set her rolling may be. Although this peculiarity has long been known to scientific men, no such observations have been made in merchant ships as would justify any specific rule on the subject. It is, however, most desirable, that information should be collected upon it, and that the attention of the owners and captains of vessels should be called to it.

Boats.—12. It is believed that the present Rules of the Board of Trade regarding boats, life-boats, and their tackle, are good in principle. The responsibility for keeping all boats in constant readiness and efficiency obviously rests on the captain, and must fix on him the blame for all neglect and its consequences. Every open boat built of iron or steel should be fitted with sufficient water-tight spaces to float her.

Anchors and Cables.—13. The system of proportioning anchors and cables by Lloyd's, and of proving under license of the Board of Trade by Act of Parliament is so far satisfactory; but as the proof-test alone cannot establish the excellence of the cable, the reputation of the makers must be relied upon.

Flap-boards.—14. In order to provide for the rapid clearance of the upper deck from water which may break over the ship, flap-boards should be fitted to the lower part of the bulwarks, sufficient in number and in area to admit of the rapid escape of the water.

Water-closets.—15. Water-closets on decks below or near the water-line may be the means of gradually and imperceptibly flooding the ship, and endangering her safety, unless the pipes and valves are strong, and are carefully fitted.

In addition to the foregoing, the Council desire to record various recommendations of Members, which appear to them to be deserving of consideration, but which have not been embodied therein.

That the course adopted in ocean mail steamers under Admiralty survey is desirable in all ocean steamers, *viz.*, that there should be two hawse pipes fitted on each bow, and a second pair of riding bitts, so as not only to provide means for readily letting go and riding by a third anchor, but also to have a spare hawse-hole and bitt on each side, in the event of either of the working hawse pipes or bitts breaking or becoming unserviceable.

That on the beams of each compartment should be painted the whole tonnage of the vessel, and the capacity of the particular compartment in tons of 40 cubic feet, and that the dead weight and measurement tonnage in each such compartment should be shewn on the ship's register before clearance.

That no dead weight should be permitted in either the fore or after sections of any passenger ship.

That all communications with the sea should be fully exposed to view, and be readily accessible to the engineers.

In the absence of any spar-deck the engine hatchway should have coamings or watertight bulkheads round it, rising at least as high as the bulwarks.

Certain portions of the ship, as for example the screw alley, might be made accessible for repairs after they had been bilged, by forcing air into them, and thus expelling the water, and such portions should be made air tight, and be in communication with force pumps with a view to this.

Spars and boats should be so disposed as to float off in the event of a wreck and form a substantial raft. Deck houses and other portions of the ship may also be so fitted as to be readily detached from the ship as rafts.

The Council desire to place on record the following extract from the minutes of the proceedings of their first special meeting, on the subject of the safety of iron ships.

"Mr. Charles Wigram (Member of Council): Assuming that the case of the *London* would come under consideration, offered to give the Council all the information that his firm could afford on the subject.

The Council decided not to take up the loss of the *London* as a subject of enquiry."

Mr. Charles Wigram: I do not know who will move the adoption of this Report. I do not wish to oppose its introduction, or to propose any motion of postponement; but still I think it is highly desirable that it should be known to the Members of this Institution that there are many of our professional Members who do not at all coincide with that Report, particularly in some of the more important parts stated in it. I may state, as far as I am myself concerned, that I am opposed to almost every resolution that is there proposed. The Papers which were circulated to the Council must, of course, be regarded as confidential, and therefore I am not at liberty to state any opinion expressed in them, nor do I feel at liberty to mention names; but I think I am justified in saying this—that at least four of our most eminent members of the Council, private builders, have expressed their disagreement with many points in this Report. As it is proposed to take a very important action based upon this Report, namely to ask for a Public Commission of Inquiry, to which Sir John Pakington has referred, I think it would be very desirable that it should be known that we do not coincide in the opinions there expressed, or else I think the result of the matter being publicly enquired into will lead to very great disadvantages to this Institution. Having said what I think, Gentlemen, I will leave the question with you.

Mr. Scott Russell: Perhaps I may make a single observation on that subject which will coincide with, I think, and carry out Mr. Wigram's view. The Council felt there might be great difference of opinion on many of these subjects, and that it was not for them to recommend legislation, but that all that they could do was to move that the subject should be thoroughly enquired into by an independent body, such as a Royal Commission, and before that Royal Commission I think I can assure Mr. Wigram that no body or part of the Council of this Institution will ever make an appearance in a corporate capacity, but that every person who appears there will be called up to give his opinion, and that opinion will rest entirely with that Commission, if it be appointed, upon its own merits. I merely say that the action he deprecates has been most carefully and sedulously avoided, and that there does not exist in this Council, nor in the minds of any of its Members, the slightest intention to act in any manner in a corporate capacity, beyond the Report, which they have just thought it to be their duty to make to you, who have appointed them (cheers).

Mr. Grantham: I did not understand Mr. Wigram to take that view in his argument which Mr. Russell seems to have imputed to him. I am not quite sure.

Mr. Scott Russell: I thought I apprehended Mr. Wigram.

Mr. Grantham: I think Mr. Wigram said he did not approve of the individual items of the Report. I understood Mr. Wigram to say so.

Mr. Charles Wigram: I intended to express it.

Mr. Grantham: I thought that was his intention, and I wished to set the matter right before the meeting. I also quite agree with Mr. Scott Russell, when he says that there was no intention whatever on the part of the Council, or if any individual entertained, certainly the body of the Council never entertained for one moment, the idea of taking any legislative action in this matter. But we have this, Sir, to congratulate ourselves upon, that whatever may be the difference of opinion as to the several items of that Report, there is one great feature presented by it, and it is this; that the minds of naval architects—and I suppose we embrace in this Institution all the best-informed men of the country—the minds of the naval architects of this Institution are fully alive to the importance of the question which has been started by our Right Honorable President. All we can do is to speak upon the practical points connected with ships;

but at the same time we have our private duties to perform, and as private individuals we may urge forward that course which I think is now contemplated, viz., legislative operation, or co-operation in this matter. This, I am happy to say, seems to be taking a very desirable turn. There were many discussions arising out of practical questions which came before the Council, which so nearly verged on, and evidently tended towards, legislation, that it was difficult to keep away from it, and the subject of legislation was continually mentioned incidentally, till at last it assumed one form, and the whole question was discussed, and took the direction indicated in the Report; and it was then considered that it was eminently the duty of the Government to take it in hand at the point where we must leave it, and this seems now to have made fair progress. Sir John Pakington has informed you that he has met the Duke of Richmond with a deputation from this Institution, the object of which was to lead out from the practical questions which are in that Report, to the further point where our united effort must cease. It may now take the form of legislation, and I firmly believe that some such step will arise out of our work. Not that I think any one wishes to increase legislation, but the great point is to simplify it, and to introduce a uniform line of action throughout. For this purpose I believe the aid of many eminent Members of our Institution will be called in to give their assistance, not as connected with this Society, but in their individual capacity. In this form, I believe, we shall render an immense service to the country, and Sir John Pakington has not said anything too much in congratulating the Institution upon the movement thus made.

As for the questions raised by Mr. Wigram, they are each of them subjects for our own private views and feelings. To say that a document like that could be composed, and that every Member of the Council shall be unanimous as to every detail, is to expect too much. We cannot be supposed to be unanimous upon everything. I must confess I am not myself clear upon all the points adverted to, and yet I give my assent to the Report as a whole. I think ultimately that our labours will result in an immense benefit to the shipping interest of this country, and especially in that department which has been particularly noticed, namely, the passengers and crews who entrust themselves in these ships.

A Member: May I be permitted to ask a question? As this is a very interesting question, may I ask the Council whether it is their intention to distribute the Report amongst the Members of the Institution at once, or whether we shall have to wait till the publication of the next volume of *Transactions* before we shall have an opportunity of shewing it? I have no doubt the Council will be able to tell us their intention in this matter.

Mr. Merrifield: It has been already communicated to the newspapers, and I have no doubt that before these meetings are over, a very good abstract of it, at least, will be in your hands.

Mr. Reed: I wish, before this subject is dropped, as I had the honour of moving the original resolution which suggested this action of the Council, to say, with reference to the remarks which have been made, that the Council were most particular during the whole of their proceedings to limit their action strictly to the terms of that resolution which was passed by the General Meeting. There were naturally, as Mr. Grantham has pointed out, great inducements to diverge from this path, but the Council most anxiously adhered to that resolution which had received the sanction of the Institution generally, and which alone had received its sanction. You will find, when you come to read the Report carefully, that the terms of my resolution have been strictly conformed to, and that we have not exceeded them in the

least degree. I need not say anything about the want of perfect unanimity on the part of the Members of the Council, simply because it is never expected that under such circumstances absolute unanimity can be secured. There was a very general unanimity, a very considerable majority of the Council agreeing with the Report which has just been read to you.

The Report was then received.

The CHAIRMAN: I will not occupy any of your time before the reading of the Papers except to recall to your recollection the rules which have been observed on former occasions as to the length of time which Papers shall occupy, and the limit of the Discussions upon each Paper. You will, perhaps, remember, that it has been determined, that the reading of no Paper shall occupy more than twenty minutes, that no Discussion shall occupy more than forty minutes, and that no single speech shall exceed ten minutes. As some time has already passed, perhaps Gentlemen will be inclined to carry out these rules to the utmost of their power; otherwise I am afraid we shall have this morning rather a long Meeting.

Since the issue of Vol. VII., the names of the following Gentlemen have been added to the lists of Members and Associates respectively:—Messrs. Carl Christian Burmeister, Charles Arthur Day, Annanias Dekke, Edward James Harland, John Reid, Edward Ritherdon, William Edward Seccombe, Thomas Summers, David Tod, William Wain, and William Wray, Members; Vice-Admiral Sir Sydney Colpoys Dacres, K.C.B., and Vice-Admiral Sir Alexander Milne, K.C.B., Associates and Vice-Presidents; Messrs. John Price, William Symington, William Poole King, John Purves, Theodor Zeysing, George Allibon, Raylton Dixon, Joseph Wheeler, junior, George Hollingum, Walter William Williamson, Jules Convers, and Charles Paul Du Buit, Associates.

It is with much regret that we have to record the death of Mr. George Moorsom, Honorary Member; Mr. Oliver W. Lang, Member; and Captain Alexander Nairne, H.C.S., Mr. Robert Bowman, Mr. Edward Humphrys, and Mr. William Carpmael, Associates of the Institution. We have to thank Mr. William Moore, Principal Surveyor for Tonnage, for the following short Memoir of the late Mr. Moorsom:—

The late Mr. Moorsom, Surveyor General for Tonnage, was born at South Shields, in 1796, and entered the School of Naval Architecture at Portsmouth in 1811. On the expiration of his term at this School—the School of Watts, Creuze, and others eminent in their profession—he was appointed Foreman of Shipwrights in H.M. Dockyard at Pembroke, but retired from the service after a period of fifteen years, discontinuing his profession in a great degree. In 1849, on the appointment of a Commission for inquiring into the Tonnage Laws of this country, Mr. Moorsom was requested by the Lords Commissioners of the Admiralty to become a member of that Commission, which on its meeting elected him as Secretary. The Report of this Commission was not adopted by Government, and Mr. Moorsom subsequently took up the matter alone, and by his skill and untiring energy succeeded in establishing the present rule of Tonnage, known as "Moorsom's Rule" and "New Measure," which leaves modelling quite free, settling (in the opinion of a distinguished shipowner, Mr. Gilmour) for many generations, a most important question. Mr. Moorsom was subsequently requested by the Board of Trade to re-enter the Government Service as Surveyor-General for Tonnage, and was appointed to that post on the 1st January, 1855. Failing health compelled him to retire from this Service in August, 1864. He removed to Priestfield, Durham, near his native place, and resided in seclusion until his death, which took place on the

15th August, 1866. Mr. Hall, the celebrated shipbuilder of Aberdeen, once speaking of him, observed, "He is a man whom every shipbuilder and shipowner has reason to respect."

Mr. Moorsom was the author of the "Review of the Laws of Tonnage," published in 1853—a work much valued—in which he advocated the adoption of an international Tonnage Law; holding the opinion that the system originated by him was a proper system for this purpose. He lived to see his system adopted by America, and it has been recently adopted by Denmark, and is now under consideration by France, and by Sweden and Norway.

Mr. Moorsom was elected an Honorary Member of the Institution of Naval Architects in 1861.

DESCRIPTION OF SOME TUG STEAMERS FOR THE GODAVERY RIVER.*

By James R. Napier, Esq., Mem. Council.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Thos. Lloyd, Esq., Vice-President, in the Chair.]

Major F. T. Haig, the engineer in charge of the Godavery Navigation Works, feeling the necessity of getting some steam tug boats and barges, drawing very little water, to carry the materials when the river was low, applied to me to assist in designing them. Their length and breadth were limited by dimensions of canal locks to 140 feet by 25 feet. The draught of water was not to exceed a foot. The load was to be carried in barges towed alongside or astern, and the power and speed were to be as great as possible.

The plans I submitted were approved of. With the permission of the Secretary of State in Council for India, I shall describe a few of the peculiarities of the tugs now building by Messrs. Randolph, Elder, and Co., at Glasgow.

It was necessary to have the propeller at the stern to enable the locks and certain narrow channels to be passed, and the boiler and fuel in the fore part of the vessel to balance it. An awning was necessary for protection from a vertical sun and tropical rains. The post for stern-towing required to be near the centre, with freedom for the tow-rope to traverse about 90° to each side round it, to allow the tug to be easily steered. These considerations led to the plans which were adopted.

The form of bow is one which Major Haig found to give very successful results in some wooden vessels of light draught, which he had built for the Navigation Works.

It is designed to give a wholly vertical displacement to the water. Its inclination from the vessel's bottom to a short distance above the surface of the water is about $9\frac{1}{2}°$, or a rise of 1 in 6.

* Received April 11th, 1867.

It is evidently a form of least resistance in smooth water for vessels whose breadth is twenty-five times their depth of immersion; for it gives the maximum of carrying power for the given length, breadth, and draught of water, and a more acute entrance than vessels usually have.

Some experiments by Sir Arthur Cotton, on the resistance of vessels covered with different substances, showed the great importance of having the surfaces smooth. Carefully made steel, besides its great strength, has this quality in a high degree. The plating has, therefore, been made of this material, and, in order to preserve its smoothness as long as possible, it has been galvanised. In the actual plating, however, neither the steel nor the galvanising is as smooth as it was intended to be, or as a little more care on the part of the manufacturers would have made it. Nevertheless, it is smoother than the painted surfaces of iron vessels, and the expectation is that it will preserve the steel and keep its smoothness longer. In one of the six barges, the immersed surface has been made of brass, and in another of painted steel, to compare their resistances with the galvanised surfaces of the other barges. Two of these would have been tried on the Clyde, but it was considered that more reliable results could be got on the Godavery, with suitable instruments, and would be permanently useful there.

The bottom plating is of cast steel $\frac{1}{8}$ inch thick, fastened to longitudinal frames placed 2 feet apart.

The awning, or roof, is made part of the structure. It is plated with galvanised steel, $\frac{1}{16}$ inch thick, resting on longitudinal frames similar to bottom, but lighter and closer, and connected with the vessel's bottom by two lattice frames placed about two-thirds of the breadth of the vessel apart.

The stresses on these frames are transmitted across the vessel at bottom and roof by steel angle-bars every 9 feet.

The roof is prevented from being blown or pulled over by diagonal braces at each of the cross bars. Its height amidships is 10 feet, made so high for the comfort of those under it, and to decrease the stresses along it, and not higher, on account of its decreasing the stability, especially when towing in certain cases from the centre post.

A short deck at the fore part contains a powerful steam capstan with large warping pulleys and anchors for getting off sand banks. In other respects they are open boats, a light floor of wood laid on the bottom frames saves the weight of beams and of thick decks. If the intended trim is realised, they will have $2\frac{1}{2}$ feet of freeboard.

There are two rudders, each about 8 feet long; one was thought to be insufficient for the quick steering which will probably be required in the rapids. They are placed

before the paddles, for want of length behind them. The tillers are long, to make the steering and steering-rods light.

The longitudinal direction of the frames of bottom and roof is evidently that which requires the smallest quantity of material, for in that direction the forces acting on the vessels to deform them are the greatest.

The stresses to which the various parts of such a structure may be subjected by known forces are not difficult to calculate with a precision sufficient for practical purposes. But my ignorance of the greatest amount of buckling which long columns of cast and of puddled steel of various sections might bear without injury prevented the fearless application of the results to many of the parts; so that the vessels are not, probably, as light as they might have been.

They are to be propelled by a pair of cylinders of 11 inches diameter and 4 feet stroke, supplied with steam at 150 lb. pressure by a boiler differing little from the ordinary locomotive type. Only the tubes are spaced wider, and the steam drum made higher, in order that less attention may be required when the river is muddy.

There are 14 square feet of firegrate, and about 650 square feet of heating surface, and it is intended to burn wood. The slides are the minimum pressure valves of Adams and Parson, now coming into use on railways.

The cylinders are cast close to each other, and surrounded by a steam case. The cranks are set at an angle of 90°, and connected by a link on their pins, to save the weight of an intermediate shaft, and get the greatest length of paddle.

The cranks, half the connecting-rods, and part of the links are balanced by a cylindrical segment-weight, to reduce or annul the stresses which their vertical vibrations would produce on that part of the structure which is otherwise most strained.

The paddle-arms have a radius of $3\frac{1}{2}$ feet to the centre of oscillation of the paddles. There is no wheel, the rims having been dispensed with, to simplify the construction and facilitate repairs. The arrangement is believed to be as light as a wheel of the same strength and dimensions.

The contractors have succeeded, by hanging the oscillating gear of the paddles on the shaft, in giving it a better support and more definite position, than the thin sides of the paddle case would afford, and in simplifying the connexion of the paddles with their arms and eccentric rods.

The paddles are at present of elm, but it is probable that some of the timbers of the district will be found to stand the heat better, and to be stronger. Steel of the same strength is considerably heavier. Their propelling surface is intended to be the greatest

which the breadth and draught of the vessel would admit of. The actual amount will not be known until they are tried. It will not be less, however, than the $\frac{1}{180}$th part of the surface of the vessel, the $\frac{1}{200}$th part of the augmented surface of Professor Rankine's theory, and it may be the $\frac{1}{130}$th of the actual surface, or the $\frac{1}{150}$th of the augmented surface, as part of it may be above the 1-foot water-line, and perhaps a part may be allowed below the bottom.

The speed which the vessels may attain will depend on the power of the boiler to raise steam with Indian woods, whose evaporating qualities are unknown to me, and on the resistances, which I have not attempted to calculate, in an exhaust pipe about 100 feet long. I expect, however, that the speed of nine miles an hour originally contemplated will be easily realised, as the boiler is of the dimensions usually supplied to locomotives, whose pistons have a velocity a third part greater than is necessary for this rate of speed, and more than one and a half times the area. Any additional speed beyond this, which the boiler may be able to supply steam for, will be all in favour of the undertaking. As more speed is expected, the strength of the machinery has been calculated to work safely at 300-horse power, or a speed, it may be, of twelve miles an hour for the vessel.

The displacement on a foot of draught is 79 tons, and about 7 tons the inch above that. The hull is estimated to weigh 45 tons, and the machinery 25 tons, leaving 9 tons for fuel and other stores. There is a probability, therefore, of the 1-foot draught being exceeded when there is no limit to the draught. When the draught is limited it was permitted to remove a quantity of their portable materials into the barges. I am in hopes, however, that little of this work will be required.

In case of collision with the rocky bed of the river, causing great or sudden leakage, I have arranged a steam pump on Giffard's principle, which is expected to discharge between 200 and 300 tons an hour.

Drawings and photographs were exhibited at the Meeting. A longitudinal and a cross section of the vessels are shown in Plate I.

DISCUSSION.

Mr. Rochussen: Does Mr. Napier know what effect was produced by galvanising the steel? Did he test the tensile strength before and after galvanising? It is a very important matter. We have had but very few examples of the application of galvanised steel, except in the cable of 1866, and in this it reduced the strength sixty per cent. If it is adopted in the construction of ships, the reduction of strength would be a very important matter.

Mr. NAPIER: I do not know what the strength of the plating or of the steel in these vessels is. I tested only some Glasgow made Bessemer steel bars, and found some of it immensely strong; and some of it intended for the same quality had only about a third of its strength. If the greatest strength could have been depended upon, the plating would have been made thinner than it is. I had every encouragement to do so, as the draught of water is everything in this case. If the intended draught can be obtained, then an immense river will be open throughout the year to navigation, instead of portions of it, and for a few months in the year, as at present. Reducing the draught of water will, I believe, save the immediate cost of canals and other navigation works.

Mr. YOUNG: Were the plates galvanised before they were put on the frames?

Mr. NAPIER: No, I believe they were not; some were, but most were not.

Mr. YOUNG: Then, when the zinc has worked off the ship, what are you going to do?

Mr. NAPIER: Nothing, or paint the bare places. They will not be worse then than old iron vessels with the paint off; and it is possible that they may be much better, as I expect that the zinc will protect from corrosion more steel than it immediately covers. The vessels may be working seven or eight years, and save all the money in the meantime if successful; and if not, the Government will have spent about £8 per ton on a fruitless experiment.

Mr. YOUNG: As far as I have seen of galvanised iron, the zinc always peels off. You cannot get an even surface with it.

Mr. NAPIER: I believe you are not far wrong. The zinc does not appear to have formed an amalgam with the steel in any pieces of the plating that I have observed.

Mr. SCOTT RUSSELL: Allow me just to say, that anybody who has not tried to build what the Yankee called "a vessel that would go over a green meadow immediately after there had been a heavy dew," and it seems to me that Mr. Napier has had a similar problem put to him—anybody, I was going to say, who has not had such a task put to him, cannot adequately conceive its extreme difficulty. I remember having the task to perform of building a steamer to go on 9 inches of water. I am sorry to say that I had to take very much the strength that Mr. Napier has been able to take in this case, and I cannot say that the plates lasted very long. In regard to this particular vessel I must say, as a brother engineer who has had the same task to perform, that I do not see how Mr. Napier could very well by any amount of capacity have got more strength out of a given weight of matter than he has there. I must say that he has done the right thing, at once and palpably in this respect. He said to himself, "Now the only element I can have of "strength is height, and I therefore take the greatest practicable and expedient height, that will not "interfere with the real use of the vessel." He found there was a place in the awning where he could put his strength without inconvenience, and he chose to put an iron awning on the top of the ship by way of strengthening it and lightening it. That, I say, was a very clever thought. Such an idea never occurred to me, I confess, though I have often had the same problem to accomplish. I had one vessel of 120 horse-power to go on the Scinde, a river with two feet of water. I launched her on the Thames in 19 inches of water, and I thought I had done a very clever thing, but it was not half so clever as the boat of Mr. Napier. What I did was this:—I took the top of the cabin, and I said, "Now, I can get as high as the top of the cabin; therefore, I will make the top of the cabin the top of my beam;" but to go higher, and make the top of the awning the top of my beam, is far above me.

Mr. NAPIER: I should like to hear some of the engineering members' opinions of the paddle arms. There is no rim to the wheel. It is all spokes. It is not a wheel at all. A wheel is a thing with a rim, and this has none.

Mr. SCOTT RUSSELL: Are the arms separate?

Mr. NAPIER: Yes, separate arms, without rims. It is as light as a wheel.

Mr. SCOTT RUSSELL: Then I must ask Mr. Napier a question, namely, what he thinks to be the value of that? because I am quite sure it has a value from his using it. As a matter of mechanical principle, I need not tell you, that we hold it to be very good, when you have a great number of parts in anything, to join them altogether, in order that they may help each other with their strength. In this case Mr. Napier has chosen a different course, and instead of letting them all help each other, he cuts them off from helping each other.

Mr. NAPIER: Exactly so.

Mr. SCOTT RUSSELL: I am sure that he has a good reason for doing that. I cannot guess what that reason is, but I will try to guess it. I think he says to himself, "If I tie them altogether for help, it will "be very good when they can help each other, but if I tie them altogether, I must tie them like marriage, "'for better, for worse,' and therefore if I so tie them that they must help each other, I may also so tie "them that they may harm each other;" and perhaps he says, "Now, by separating all those spokes, when "I come into difficulty, or into deep water, instead of the piece which joins them being exposed to every "kind of derangement, by making them quite detached, I shall avoid all the chances of injuries to any but "one at a time." If that be his principle, I at once admit that it is a very clever and a very ingenious principle.

Mr. NAPIER: I shall give Mr. Russell my reason for doing it. An outer ring or rim was inadmissible on account of the small draft of water. There might have been a ring inside the paddles; if so, the arm between it and the centre, or boss, being under a uniform bending moment, would be most economically made of uniform breadth and thickness, equal to the breadth and thickness at the ring. Many paddle wheels, however, are not so made; the arms are light, and the necessary strength has to be put into the ring, and often also into a great bracket on the arm itself. When the arm is made strong enough of itself to resist the uniform bending moment, the ring may be light. I found, however, that when the quantity of the material, which it was necessary that this ring should have, was added to the arm, I had the requisite strength with little, if any, additional weight, and a simpler and more easily repaired propeller. I think Mr. Merrifield can prove, mathematically, that the principle is correct.

The pump is one of Giffard's, from which I expect great results.

The CHAIRMAN: There can be, I am sure, but one opinion as to the value of the Paper which Mr. Napier has read, and I beg to return him our thanks.

ON THE STOWAGE OF MERCHANT SHIPS.*

By Nathaniel Barnaby, Esq., Mem. Council.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Thomas Lloyd, Esq., Vice-President, in the Chair.]

The object of this Paper is to illustrate by some examples the recommendations of the Council on this subject in their recent Report relating to the safety of iron ships. That Report says: "The stowage of a ship, whether done by contract or not, should be done "under inspection of the captain of the ship, and should be conducted under his own "orders only; and he alone should be held responsible for the good stowage of his ship. "Ships are often very badly stowed, the weights being sometimes too low, thus causing "them to roll with such rapid and violent motions as to carry away the spars, and "otherwise endanger the safety of the ship, and at other times too high, thus making the "ships crank and liable to turn over. A ship may, however, generally, whatever her "form, be so stowed as to avoid both dangers. As the character of the ship in these "respects varies, so does the number of oscillations she would make per minute, if she "were set rolling in still water, by men running across her deck, or other means, and "then allowed to come to rest; that is, if the ship be crank, the number of oscillations "per minute will be few, and if she be too stiff they will be numerous; but under the "same conditions of stowage, the number will always be very nearly the same, whatever "the amount of the impulse to set her rolling may be. Although this peculiarity has "long been known to scientific men, no such observations have been made in merchant "ships as would justify any specific rule on the subject. It is, however, most desirable "that information should be collected upon it, and that the attention of the owners and "captains of vessels should be called to it."

We are all of us acquainted with ships designed advisedly with such proportions, that, when masted and empty, they are incapable of standing upright. But their lading altogether transforms them, and these same ships become, under some circumstances of

* Received April 11th, 1867.

lading, dangerously stiff. This fact is sufficient to show to how large an extent the behaviour of a ship at sea is independent of the designer, and dependent only on the stevedore or packer.

Indeed, I do not think I should be doing any injustice to our profession as naval architects, if I were to say, that the behaviour of merchant ships at sea is more dependent upon the packers than upon the designers.

This is, I think, sufficient justification for the expression of the opinion the Council have given in the matter of stowage, and may be held sufficient apology for me, in presuming to deal with a matter in which I have had so little direct personal experience.

In Her Majesty's Service the designers are, it is true, directly responsible for the proper stowage of their ships, because they assign the position of all the stores and other weights carried; but the variation in the nature of the cargoes carried by merchant ships introduces considerations with which they are not familiar, and I therefore can only hope to assist in this matter by an exposition of principles so far as they may be practically applied by the packers, and by such illustrations as my own experience may have supplied.

The able Papers read by Mr. Froude, Professor Rankine, Mr. Crossland, and other gentlemen, on the rolling of ships, have done much to enlighten the naval architect in the matter of stowage, and may be expected to influence the forms of future ships; but, unfortunately, not only is the action of the designer limited in its influence on the behaviour of the ship he designs, for the reasons already stated, but there are many ships which have no designer. They are the growth of an idea of the owner, grafted on some existing ship, and fashioned by the skill of the mould-maker, aided by the naturally graceful tendencies of the materials, into some sort of shapeliness.

The influence of the architect is therefore so limited, and we are thrown so entirely into the hands of the packers, that we are most anxious to give them the benefit of any knowledge of the subject which we may possess.

The question then arises, How are we to provide that the packers have all the knowledge which is attainable, and have at the same time sufficient personal interest in the success of the ship to make them use their knowledge carefully and conscientiously?

Only, it seems to me, although I speak here with much diffidence, by examination as to competency, and by the existence of some directly personal interest in the success of the ship. These two conditions point to the captain of the ship, and to the captain only. He has already to pass an examination as to competency before the Board of Trade, and he is therefore accessible to existing and increasing knowledge on these

subjects, through their influence; and he has generally some share in the money earned by the ship. On this account the Council says, "the stowage of a ship, whether done "by contract or not, should be done under inspection of the captain of the ship, and "should be conducted under his own orders only; and he alone should be held "responsible for the good stowage of his ship."

It may be objected to this recommendation that it will involve in many cases either delay in the ship or absolute prohibition of leave to the captain. The ship is at home only one or two months after a long voyage, and she commences to receive cargo almost immediately after her arrival. If the captain is required to superintend this, he will have no time to spend with his family, and the duties would become so distasteful that good men would abandon the service. Under these circumstances, it is the practice for the chief mate to superintend the packing. It is true that the personal feelings of the chief mate are not much considered in this arrangement, but that is of no importance. The chief objection to this practice is, I think, that the chief mate has neither the experience nor the direct personal interest in the ship which the captain has. In services like those of Messrs. Green and Wigram, and other large shipowning firms, this argument would hold with much less force, because the chief mate is a permanent officer whose interest is to some extent identical with that of his employers; but so far as we naval architects are concerned, we see no way which would be generally so satisfactory as that recommended by the Council.

It is most unsatisfactory that such important public interests should be imperilled by trusting to a mere leading man of labourers, whose responsibility ceases when he has crammed the ship full of goods at so much per ton. There can be no doubt that, in the course of time, a shrewd active man, employed always in stowing the same type of ships, trading always to the same ports, and carrying the same descriptions of cargo, would, without any knowledge of principles, stow as well as the captain could, perhaps even better. But a vessel of a different type, propelled, let us suppose, by steam instead of sails, and built of iron instead of wood, must depend more for her safety on the chapter of accidents than on the knowledge and skill of the stevedore. But if the captain were encouraged to enlarge his knowledge, and were compelled to take all the responsibility, his nautical experience, his superior intelligence, and his general knowledge would be a far better security.

The designer of the ship, supposing her to have had one, is the proper person to say where and how the first cargo should be stowed. No one else can say, with any certainty, what her capabilities are, and how they may be best brought out. After her first voyage, which is always the most dangerous, the captain gains experience, which

he treasures up, and which he should be best able to turn to practical account in her subsequent undertakings.

In successive voyages, as the character of the cargo changes, and the designer is no longer accessible, the captain must decide how it should be stowed. It is the main object of this recommendation of the Council to assist him by showing him how he may use the experience he acquires (either directly, or through the records in the ship's papers), as to conditions of stowage and behaviour, in order to ensure equally good behaviour with very different cargoes.

If I give at once an example of such an experiment as that referred to in the recommendation of the Council, we may be able to see more clearly than by any other means the nature of the operation, and the extent of its probable usefulness.

I wish the example had been of sufficient magnitude to show the greatest amount of mechanical difficulty involved in setting a large ship in motion in still water. It is thought by some people that this will be considerable. I do not share this fear; but I am not in a position to say from experience that it is absolutely groundless. I would, however, suggest the following simple mode, which appears to present but little difficulty, when the vessel, stowed, or partially stowed, is lying by the wharf-side, in a tideway, or in a wet dock. Secure the ship to the wharf-side by a chain with a slip, when she is lifting by the rise of water. As she lifts, she will, of course, incline towards the wharf.* If released, when she has been thus heeled over a few degrees, she will make a few oscillations, and then come to rest. It does not matter what the extent of the inclination is, provided some five or six oscillations can be counted, and the time they take noted in seconds. The number of oscillations in a given time, say in one minute, will be found to be the same practically, whether the vessel oscillates five times or twenty times before coming to rest. The vessel on which this experiment was made is the *Madeline*, the yacht of Captain Robert Hall, superintendent of Pembroke Dockyard. I owe the experiment to his personal kindness.

The *Madeline* is about 50 feet long, over all, and 12 feet wide, with 4 feet 8½ inches draught of water, and 26 tons displacement. The exact particulars, with regard to her statical and dynamical stability, &c., are given in the accompanying tabular statement, prepared for me by Mr. Froyne, one of the members of this Institution.

The vessel was first heeled over 10°, and then released. The time occupied by five complete oscillations (from port to starboard and back again to port being one oscillation) was 21 seconds. She was then heeled over to 15°, and it was found that

* The force required is not considerable. In a ship like the *Achilles*, weighing about 9,500 tons, the strain on the securing chain would be only about 80 tons, at an inclination of 5°, and about 160 tons at 10°.

although the rolls were deeper and more numerous, five complete oscillations took exactly the same time as before.

A weight of 6.6 cwt. (about $\frac{1}{80}$ of the whole displacement) was then raised from the deck 12 feet, and secured to the mast. The ship was set rolling as before from both 10° and 15° inclination. The time of performing five oscillations was in both cases 23 seconds. The weight was then raised to 20 feet above the deck. The ship was again set rolling from 10° and from 15°, and the time of performing five oscillations was 26 seconds in both cases.

The time occupied by a single oscillation was thus in the three cases 4.2, 4.6, and 5.2 seconds respectively, and the number of oscillations per minute was respectively $14\frac{2}{7}$, $13\frac{1}{23}$, and $11\frac{7}{13}$. The several lengths of pendulums which would oscillate in these times would be 14.38 feet, 17.25 feet, and 22 feet. The differences in the time may appear to be too trifling to be practically useful, but any gentleman may see by timing the pendulums, which I have provided for the purpose, that the differences are very readily seen. These pendulums were constructed from the formula that their length should be the square of the period multiplied by .8154. Thus $(4.2)^2 \times .8154 = 14.38$; $(4.6)^2 \times .8154 = 17.25$; and $(5.2)^2 \times .8154 = 22$.

The students at South Kensington, when asked to give the time of five oscillations from the pendulums, in ignorance of the times given by the ship, gave me without hesitation 21″ and 23″ and, although with a little hesitation, I think, in the last case, 26″, *i.e.*, the exact times of the ship.

If we examine the changes which had taken place in the ship by shifting the weight referred to, we shall see, that whereas the centre of gravity of the vessel was 2.2 feet below the metacentre at the time of the first experiment, it was only 2.05 feet at the time of the second, and only 1.9 feet at the time of the third; and the stability of the vessel varied in this same proportion. Thus when the stability was 2.2, or say 22, the vessel made about $14\frac{1}{2}$ oscillations in a minute; but when it was reduced to 19, it only made $11\frac{1}{2}$ per minute. Had the weight been heavier or been carried higher, we should have found the number of oscillations still decreasing, until the centre of gravity being raised as high as the metacentre, the number would be reduced to nothing, and the vessel would turn over.

It will, however, be said: you have stated only a part of the case. The raising of the weight increased the moment of inertia, as well as reduced the stability, and the alteration in the time is due partly to that cause. This is perfectly true. The radius of gyration is, in the three cases, 5.62, 5.94, and 6.47 respectively, and the corresponding moments of inertia are 824, 921, and 1092.

We may, indeed, by winging the weights, make the time the same, in two cases in which the stabilities differ largely. This method cannot, therefore, be said to be a fair measure of the varying stabilities in a ship. It is a measure of the extent of winging and of elevating weights considered together. Raising weights slows the time, and winging weights does the same; and on this slowness, however produced, the good behaviour of the ship in a seaway largely depends. It is, therefore, useful to know what the joint effect is, even although we should be unable to distinguish between the relative effects of these two causes of slow or rapid rolling.

This much at least is certain, that neither dangerous crankness nor excessive stiffness could fail to be discovered by this test before the ship left the docks, and a record of the times of oscillation, and of the corresponding behaviour of particular ships, would not only be useful in this way to the captain and owner, but the naval architect would, in the course of time, be able to draw from this experience invaluable lessons.

We may be asked, Can you not do more than this for the packer? Can you not lay down some specific rules for his guidance? We can, and we cannot. We can give specific rules to the naval architect by which he could stow the cargo, supposing it were all at his disposal, just at the moment he wanted it, and that he could place it where he pleased. But we cannot give rules which the captain or stevedore could practically use, unversed as he is in scientific knowledge, and embarrassed by having his cargo coming to him upside down, as it were, the light goods having to be stowed just where he wants heavy ones. There are, however, a few general considerations which should never be forgotten by those who have to stow ships.

It should always be borne in mind, for example, that dead weight cargo is more dangerous than any other, and requires greater care.

It may be considered that light freight goods require, on an average, 80 cubic feet of stowing space for one ton avoirdupois, and dead weight goods only 35 feet to the ton. Solid iron actually occupies only $4\frac{2}{3}$ feet to the ton. It is reckoned, I believe, that in the hold of a ship, stored and provisioned for an over-sea voyage, there are about 67 cubic feet of stowage room for every ton weight of cargo to be carried in it. If, therefore, all the cargo is dead weight goods, one-half the hold must be empty. If it is all iron, only about $\frac{1}{15}$th of it will be occupied. If the ship has been designed, as she probably has been, with a view to cargo of uniform density, filling the entire hold, then the proper conditions of lading can only be met by stowing this supposed cargo of iron, occupying only $\frac{1}{15}$th of the space, exactly in the centre of the space, *i.e.*, its centre of gravity should be in the centre of gravity of the hold, and the supports for it should be spread over the whole surface of the bottom and sides. If this is not done,

if the iron is spread over the floors, the ship will inevitably strain herself to pieces should she get into bad weather. It is not often that ships, not specially designed for it, have to carry such a cargo as this; but there is always a certain approximation to it, and the following general principle is always applicable. Let the position of the centre of gravity of the entire cargo under hatches be determined by the designer, and registered in the ship, and let the captain aim always to stow his hold so that this height of centre may be preserved. This rule is applicable not only to the position of the centre of gravity considered vertically, but also to its position considered longitudinally.

A dangerous practice is sometimes tolerated of bringing a ship to trim at the last moment by stowing heavy goods at the ends of her. This is fatal policy, and has been the ruin of many a good ship. In this case also the designer of the ship knows where the centre of gravity of the cargo under hatches should be in order to bring the ship down to her load-line and to her proper trim. The captain should know this also, and should stow from this centre uniformly right and left. Then, when the hold is full, the ship will be to trim. Of course, the more nearly the trim of the hull of the ship when light agrees with the designed trim when loaded, the nearer will this cargo of lading be to the centre of buoyancy of the ship. If the trim when light were the same as the trim when loaded, a safe rule in loading would be to take care not to alter the trim at any stage of the operation. Usually, however, ships swim considerably by the stern when light: the centre of gravity of lading is, therefore, obliged to be before the centre of buoyancy, and the ship should in this case go down gradually and steadily by the head as she takes in her lading. I cannot think it would be difficult, were this information as to the centre of gravity of lading supplied, to make every merchant captain understand his duty in connexion with it, and the examination by the Board of Trade might be made to include some test of his knowledge on the subject. It is certain that neglect of simple precautions is the cause of frightful disaster, and anything we can do, or which the Board of Trade can do, to instruct captains, and to fix on them the responsibility, is a public duty of the highest moment.

I have only one other remark before I conclude. The Council has said that rapid and violent motions in rolling are associated with low weights. I am in a position to give an illustration of this from ships in the Royal Navy.

The wooden iron-clad ships have, as a rule, low weights. The *Prince Consort*, *Ocean*, *Caledonia*, *Research*, *Pallas*, *Lord Clyde*, and *Lord Warden* have all of them low centres of gravity and great stability. We find that they all have at the same time rapid motions, and that those which roll most rapidly roll also most deeply. The ship which has the character of being the worst roller in the Fleet is the *Prince Consort*.

Her centre of gravity is six feet below her metacentre. The consequence is that when the surface of the water on which she is floating becomes inclined by the passage of a wave across her, the centre of buoyancy, or the centre of gravity of displacement, moves out towards the raised side of the water, to an extent proportional to the depth of this centre below the metacentre, and creates a lever proportionately long and powerful for forcing over the ship to the same inclination as the surface of the water has taken. As the centre of buoyancy is raised nearer to the metacentre this action diminishes, and we find in the *Achilles* and in the *Bellerophon*, where the stability is much reduced, a remarkable steadiness of platform, or small susceptibility to changes of water surface. The *Achilles* has this quality in the greatest perfection; and we find that the distance between her centre of buoyancy and metacentre is only 3 feet. In the *Bellerophon* it is 3.28 feet. Another noteworthy fact is that the distance above referred to, between the centre of gravity of displacement and the metacentre, requires to be less in an iron-cased ship than in an ordinary ship. Take for example the *Orion* and the *Prince Consort*. The distances between the metacentre and centre of buoyancy are the same, yet the *Orion* is said to behave well in a sea-way in this respect, and the *Prince Consort* badly. This is due partly to the fact that the disturbing power in the *Orion* is 6 feet multiplied by 5,100 (her displacement), while that in the *Prince Consort* is 6 feet multiplied by 6,700; but it appears to be due still more to the very large increase in the moment of inertia of the ship due to the armour-plating—an increase which has the effect of keeping up the rolling for a long time. The periods of rolling of some of the ships I have referred to, in disturbed water, but all similarly circumstanced, are about as follows:

	No. of complete Oscillations per minute.	Average angle of roll each way.
		Degrees.
Achilles	5	$7\frac{1}{2}$
Bellerophon	8	9
Caledonia	11	14
Lord Clyde	11	20
Pallas	13	18
Wivern	$14\frac{3}{4}$	$25\frac{1}{2}$

MADELINE YACHT.

Principal Elements and Calculated Results.

	ft.	in.
Length between the perpendiculars	42	6
„ over all	49	6
Breadth, extreme	12	0

		ft. in.
Draught of water {	forward	3 7
	aft	5 10
Length on load-line		43·15 ft.
Breadth at load-line		11·6 ,,
Depth in midship section from load-water-line to lower edge of rabbet of keel		3·6 ,,
Depth of keel below lower edge of rabbet		1·3 ,,
Area of load-line, or plane of flotation		378·5 sq. ft.
Tons per inch immersion at load-line		·9 ft.
Area of greatest immersed section		33·1 sq. ft.
Displacement in cubic feet		913·6 ft.
,, in tons		26·1 ,,
Metacentre above the centre of buoyancy		3·54 ,,
,, ,, load-line		2·03 ,,
Centre of gravity of yacht below metacentre		2·2 ,,
,, ,, load-line		0·17 ,,
Moment of stability to 10° heel by metacentre		9·96 ft.-tons.
Point S from middle		·2 ft.
Moment of statical stability to 10° inclination, by Atwood's formula		9·82 ,,
Dynamical stability to 10° heel		1898·88 ,,
Sails, area of		1381·6 sq. ft.
Centre of effort above load-line		19·9 ft.
Sails, moment of, round load-line		27502·56 ,,

Experiments on Rolling.

Table *showing actual performance in six experiments, change in conditions being caused by moving weights* (6·6 *cwts.*) *in a vertical direction along the mast of the vessel.*

	No. of Experiment.	Position of Weights.	No. of Oscillations.	Time of whole No. of Oscillations.	Period of each complete Oscillation.	Angle of Heel.
				Seconds.	Seconds.	Degrees.
1st condition	1	On deck, or 3 feet 3 inches above load line ...	5	21	$4\frac{1}{5}$	10
	2		5	21	$4\frac{1}{5}$	15
2nd condition	3	12 feet above deck, or 15 feet 3 inches above load line	5	23	$4\frac{3}{5}$	10
	4		5	23	$4\frac{3}{5}$	15
3rd condition	5	20 feet above deck, or 23 feet 3 inches above load line	5	26	$5\frac{1}{5}$	10
	6		5	26	$5\frac{1}{5}$	15

Centre of gravity of yacht below metacentre, 1st condition	2·2	ft.
,, ,, ,, 2nd ,, ...	2·05	,,
,, ,, ,, 3rd ,, ...	1·9	,,

DISCUSSION.

Mr. Charles Wigram: I do not question, Sir, the importance of the subject to which Mr. Barnaby has referred in this Paper. He has alluded to real and practical difficulties, and as I have some knowledge, and have had some experience, of the stowage of ships, perhaps I may be allowed to say, that I feel very great doubt as to whether any of the suggestions which he has made would be found practically of any real avail. If in designing a ship we had a perfect knowledge of all the weights that we were to carry, we should have no difficulty. In a ship that is designed as a ship of war, for instance, you know exactly, almost to a pound, every weight you have to carry, and therefore the difficulty does not exist, because you may place your weights by calculation so as to give a perfect ship. But our real difficulty in designing merchant ships is in the variety of the cargo we have to stow. Supposing our cargo were to be an entire dead weight, such for instance as a cargo of copper ore, there the difficulty would not exist. We could, as the practice is, put in a platform upon which to build up. The difficulty, in fact, in a case of that sort does not exist. In a ship, belonging to ourselves, of about 300 tons, we used to carry about 600 tons of copper ore in safety and for several voyages. We sold her a few years ago. She was 25 years old, and had been employed for several years in the carrying of copper ore. But when we turn to general merchant ships the difficulty meets us at once. A shipmaster or a shipowner generally knows that his ship should have about so many tons dead weight; that is to say, he would like to have so many tons of dead weight, and he would tell his brokers to get him so many tons of dead weight. But dead weight is not always to be got when you want it, and this constitutes one very great difficulty: another is, that you cannot collect your whole cargo before you begin to load. Merchants are not content to have their goods kept waiting. Goods, especially goods in transit, are sent down in a barge, and probably are alongside the ship before you hear of them. The merchants come to your broker and say "Will you take such and such goods of mine that are alongside?" and if you cannot take the goods in at once, away the merchant goes somewhere else, and you lose the goods. Therefore you must take in everything when and exactly as it comes to you. Now, to give you an instance of the real practical difficulties which are met with in stowing a ship, I have here a "Freight-engagement Book" lent me by a broker. It is not a book belonging to our brokers, though one of the ships mentioned here was one of our own ships. I happened to be shown the book and requested permission to produce it to the Meeting. The ship was the *William Hasleden*, of 896 tons. Her first engagement was made on the 4th of June; she loaded for Canterbury, and sailed on the 4th of August. It begins with 50 tons of implements, 40 tons of wire, 60 tons of wire; "17th of June 50 tons measurement and wire." I do not read every item; on the 24th there is a very miscellaneous lot: "30 tons of furniture and anchors." I will not trouble you with the whole of these, but I come down to the last. On the 18th July, when the ship was very nearly filling up, having begun to load on the 4th of June, I find "15 tons hogsheads." On the 20th, "measurement and weight," there is no quantity given. On the 21st "40 tons of slates and bricks." Now really, I think, whatever examinations you may put a captain through as to stowing his ship, any man might be excused if he gets his ship out of trim in loading such a cargo as that, and this is taking, not a particular case, but really a very common sort of cargo with ships loading to the colonies. In fact, you may take it as a general cargo. The difficulty is increased, again, when you come to steamships, because the steamships in the regular trade—the vessels from the Continent—come into the Thames, and are not there, in many cases, more than sixty hours. You have, in fact, to discharge one cargo on one side, and take in another on the other.

Therefore, you are almost placed at the mercy of the trade as to how you are to stow your ship. The utmost you can do is to make the best arrangements that the circumstances will admit of, and it is only by continually watching that you can do anything at all, or get the ship into anything like trim. Really, the more I see of it the more astonished I am that a ship is not always out of trim. Therefore, I think you will see the utter impossibility of having examinations, or of captains passing examinations, or of laying down any definite rule that will be of any real practical use. Of course the knowledge that there is such a thing as a metacentre, and that there is such a thing as a centre of gravity, is a necessary point. I quite believe that some captains really do not know that there are such things. Certainly they ought to have some idea of them, but beyond general idea I really think you will find it quite impossible to lay down any regulation.

Mr. Scott Russell: I do not know, Sir, whether I more highly value the admirable theoretical views which Mr. Barnaby has given us in that Paper, or the thoroughly practical considerations which Mr. Wigram has brought to test and to illustrate his argument; and I would say, that I never saw a more striking example of the usefulness of this Institution, than the exact and direct antagonism which we have now had. Will you allow me to contribute my mite to that value by simply showing how at once I will reconcile these two opposite Gentlemen? I admit the gravity of, and the unescapability from the fix into which a captain loading his ship in dock is put; I have often had to endure it in my own ship. After making all my charming calculations, and charming plans as to the quality of my ship, I have seen the stuff go in pell-mell, just as it came, and found that in the end, when the ship went to sea, there had been put—because it came at the last moment, and for no other reason—a great quantity of heavy stuff right on the top of the cargo; and it was not at all to me a matter of surprise, that when she went into the Channel, in one good jolly lurch all this heavy stuff on the top went over to the lee-side, and there was an end of all the good qualities in the ship. Very well, granted; that is so. But, Gentlemen, is it the rule of life that because a thing is extremely difficult, therefore we must give it up altogether? I hope not! I hope not! And now, when Mr. Barnaby was reading his Paper, I said to myself, "Bless me! If the captain is to understand all these words, and to make all those calculations before "he can take in his cargo, what a precious deal he has got to do!" Very well; then I say that Mr. Wigram had Mr. Barnaby close and fast in a fix, but Mr. Barnaby has a way out of it, which he has not mentioned, and I think, therefore, I will mention it. Mr. Barnaby has this view; he says, "I think the ship's papers might contain—by law if you like—information from the builder which is not now given to any captain." Now, Gentlemen, I can tell you from practical experience that in some countries with which I am acquainted, certain ships never go to sea without there being, as an imperative part of that ship's papers, a complete set of drawings, not showing the calculations, but showing the result of those calculations, and marking the centre of weight of the ship, and the weight which ought to be stowed in each part of the ship, in order to give her the qualities which the constructor knows she ought to have. Now, I ask you whether it would not be fair to the captains of this country to provide that no ship should ever go out of the shipbuilder's hands, without having a drawing of the ship, showing the capacity of every individual hold between every couple of bulkheads, showing the centre of gravity of that hold, showing the centre of gravity which the stowage of the cargo ought to have; and then the captain, in looking at this, would say, "This hold can carry so much dead weight, and there is room for so much bulk; this can carry "so much dead weight, and so much bulk,—that can carry so much dead weight, and so much bulk,— "without putting the ship out of trim." If he had this knowledge, I do not say that he could control the

cargo, but he would have a sort of good expectation beforehand of what he would like to see, and as soon as the boat of cargo that he wanted to have in a particular place came alongside, that captain would have the part of the ship settled in his own mind where that particular thing ought to go. Now, I say, that the British captain ought to have that information afforded to him; and I say also that if he has not that information afforded to him, he is not solely responsible for the performance of his ship. Now, Sir, that is one way in which Mr. Barnaby's information might be given, and Mr. Barnaby gives another way, which I think is very good. Suppose the captain says to himself, when his ship is three quarters laden, and there comes a great lot of stuff alongside, "Now, what shall I do? What condition is my ship in? I am afraid she is much too full already!" What has Mr. Barnaby told him? Mr. Barnaby has told him that if he will get a lot of the lumpers who are going to put the cargo in, and compel them to run across the deck two or three times, and then count how many times the ship swings in a minute, that will tell him whether his ship is too full, or too crank. Well, now, Gentlemen, I can tell you that that is a test which I myself have applied with the greatest ease, not for the purpose of stowage, but to see whether I had made a ship as I intended her to be, and I say that we are much obliged to Mr. Barnaby for giving us such a very simple test. Therefore, I, for one, must give him my profound thanks for what I think will be, in the future, the practical value of his suggestions and experiments.

Mr. GRANTHAM: May I suggest for one moment that, as our time is passing so fast, and we have but very little time left to go through this long list of Papers—the three Papers which follow—three, four and five, which all come under the same class, should be discussed at one time? I am afraid, unless we do this, that we are going to miss some most important Papers.

Mr. COWPER: I wish to offer one or two observations on this Paper, and to repeat a suggestion which I made on the stowage of ships last year. I think we are deeply indebted to Mr. Barnaby for his excellent observations and suggestions with reference to obtaining the times of the rolling of ships. I think when the time of a certain ship is found, there is no doubt that the stevedore, or captain, can imitate the circumstances which will give the best result by so stowing the weights as to give, as near as possible, the same time. Now, I do not mean that the stevedore can be expected to know much about drawings, and if he did, I do not think he would carry in his mind the exact proportions of weights in the different parts so as to give the exact right centre, but at the same time we ought, as far as possible, *having first the knowledge* of what should go in the different parts of the ship, to give that knowledge in as *plain*, as *practical*, and as *useful a form* as we can. I do not see the least objection to painting on the inside of the ship—if you like on every deck-beam, or if you like on each compartment—*the weight that should go into that compartment*, with a mark on the side of the ship showing the *height* and the centre of that weight. If the stevedore has too much weight in already, he must not put more at the bottom, although bricks may come. No person in his senses would stow bricks, so as to make the vessel go to the bottom. We wish to improve the stowing of ships, and we must do it in the way which is most practicable. I venture, therefore, to repeat the suggestion I made at the last Meeting, that these *marks* should be placed on *each compartment of the ship*.

Admiral ELLIOT: I have witnessed myself the consequences of dead weights being placed in ships at Gibraltar. A question I wish to ask is this,—we have had a very able Paper read, a great deal of which has been connected with the rolling of ships, a scientific subject independent of merchant ships altogether, and certain laws have been laid down. I wish to ask the question whether there is anything new in those

laws, or whether those laws have not always been in existence, and whether years and years ago we did not know the effect that would be produced in ships by placing the centre of gravity too low or raising it too high? It has something to do with a Paper I am going to read, and that is why I ask.

Mr. BARNABY: These rules have been known for many years; our object is to make them more extensively known.

Mr. T. WESTHORP: I regret, Sir, that I was not present when the question of the stowage of ships was brought under the notice of the Meeting of last year. The subject is a most important one, and I feel confident that the Committee of Council would not deem it the less so, could they see, spread out before them in Trafalgar Square, the miscellaneous parcel of goods one is expected to pack away on board a ship loading in the Port of London, and which, after the tossing and tumbling of a four or five months' voyage, are "to be delivered in the like good order and well-conditioned" at the antipodes.

For a moment or two let these have your attention. Huge locomotives and railway bridges, marine boilers of unearthly form and immense weight, with butts of oil and bales of our finest fabrics, scrap-iron and cases of delicate instruments or works of art, agricultural engines and millinery, sulphuric acid and confectionery, lucifer matches and gunpowder, in short, something of everything "to eat, drink and avoid," and all these, say 2,000 tons, to be crowded into the hold of a ship 1,000 tons register. Surely, if these are to be taken round the world with safety to ship, crew and passengers, it is a matter of no small importance that they be stowed with regard to their proper position, and that there should be found persons who know where and how to place them. I am very glad that the able Paper we have heard has been read, because I think the subject is fraught with great difficulties, and very many that have not been looked at here to-day. I am quite satisfied that the best way of getting over a difficulty is by setting ourselves to understand it. Now I can only wonder that the Gentlemen who have designed some of our most splendid vessels have not brought this question before the public ere now, for it is a matter of great moment that the cargo of a ship should be so placed as to make her in every sense seaworthy. I believe that, in the case of ships carrying troops, or passengers, Government requires a certificate with regard to the pumps, masts, sails, and all the paraphernalia of the general outfit of a ship, but I do not know that they say much about the stowage of the cargo, which, if improperly stowed, would not only cost the owner a large amount of money, but might also cost the lives of the passengers; and it therefore becomes a matter of great importance that it should be looked into. Now, with regard to ships carrying dead weight, I am quite sure that a mistaken notion has gone abroad, and that there is a great and quite unnecessary fear, of carrying what is called "dead weight." And by the way, with regard to this, I think one important matter to begin with is, that captains should know what dead weight is, and how a solid mass of railway iron,—dead weight,—may be so placed in a ship's hold as to represent and in no way be more injurious than measurement goods. I say take any of our finest ships, any of our sharpest clippers, and with a miscellaneous cargo load them down to the proper draught of water, and you may with comfort and perfect security load those ships down to the same draught of water with a cargo of any dead weight you please. There is no reason why it should not be done again, for it has been done with many ships. I do not believe there is a seaworthy ship on the ocean, which is not capable of carrying for six months, or longer if you will, a cargo of dead weight. I speak with all deference, but I think, Gentlemen, you will find, if you come to enquire into it, that a large majority of our captains know very little about the stowage of ships at all. There is one thing which I will throw out as a suggestion,—and I think it is

important,—and that is, that young men, now the second and third officers, but who by-and-bye will be the commanders of our ships, should be placed in the hold of the vessel, and taught something with regard to the stowing department. If you go on board the ships loading in the docks in London, you find there is scarcely anybody who pays attention to this. Mr. Wigram, and others, who know the importance of the good stowage of a cargo, look after it themselves; and I am quite sure, that if you take a ship of Messrs. Wigram's, Green's, or others, where the officers are so employed, you will find that the cargo is put in better position, that less damage is done, and that the safety of the ship is better ensured. I am quite aware that there are a thousand difficulties to be contended with, but I rose just for the reason, that I wanted to shew the importance of having young men, who are officers, in their various departments, taught to understand the stowage of ships, and that many of them pay but little attention to it at the present moment. If the Committee of the Council will, during the coming Session, put before the shipowners of this Port of London the importance of paying greater attention to the stowage of ships, I am sure it will do good.

Mr. Scott Russell: I ought to mention that the Gentleman who has just sat down is one of the largest and most experienced loaders of ships out of the Port of London, and that he has fully occupied himself with this subject. Therefore I think that we have had from him most valuable information.

Sir Edward Belcher: I think the question we have to deal with is rather the science of sailing of ships than that of lading. It has been my fortune to command vessels which might really be termed merchant vessels as well as ships of war. I commanded, as Gentlemen here present know, the greatest beast in Her Majesty's Navy—the *Samarang*. That vessel, when she came into my hands, had once gone 11 knots, when she lost her three topmasts. I believe she never before went 7 knots close hauled. I had stowed in that vessel every description, as you may call it, of cargo. I had in her 960 fathoms of iron chains, running from an inch up to the ship's cable, and when that vessel was stowed, and ready for sea, she had her copper immersed 6 inches. It was on a Sunday; the Admiral telegraphed to the Admiralty to know what was to be done, I having refused to go to sea with the ship in such a condition. The answer was, "The Captain will use his own discretion," and before twelve o'clock that night 96 tons of ballast were taken out of her bottom, and she was re-stowed in a condition to go to sea as a yacht. I had the satisfaction of getting 10·6 on the wind out of that ship, and 12·6 off. I formerly had another vessel, the *Sulphur*. I found her perfectly unmanageable, and the report was you could do nothing with her. She would neither wear, stay, nor do anything else properly, and the rudder made such a noise, and shook the ship so tremendously, that the chronometers were not safe. In four-and-twenty hours that ship was changed entirely in her stowage, and she became as easy a ship as you could meet with. Therefore I say, that if you can point out to the masters of vessels, that they are to stow their cargo according to the rules which have been suggested by the Council, and have each section marked as calculated to hold so much and no more, you have advanced a certain step;—and I believe your masters of merchantmen are as clever as our masters of ships of war, and I have no doubt that we shall have vessels in the mercantile service in the course of a few years, when these things are better looked to, which will be quite as safe, and easier, than our ships in the Navy.

ON THE PROPER FORM OF SHIPS.*

By John Bourne, Esq., C.E.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Thomas Lloyd, Esq., Vice-President, in the Chair.]

The proper form of ships resolves itself into two main points of inquiry—first, the determination of the shape which will enable vessels to pass through the water with the least resistance; and second, the determination of the form of hull or of the arrangement of materials which will enable most strength to be obtained with least weight. Fortunately, neither of these problems is very difficult of solution, and together they form the groundwork of the whole science of naval architecture.

When a vessel moves through the water, it is plain that the water must be opened before and closed behind her, by which act power is consumed; and, formerly, most of the power expended in propelling a vessel was supposed to be lost by thus moving the water. It was in this belief that, in 1853 and 1854, I built several vessels upon what I called pendulum lines, which were lines of such a form that each particle of water which was encountered by the stem was moved gradually aside, in precisely the same manner as if it were suspended by a pendulum rod, and were beginning to move sideways in its arc by gravity; and as if the motion, which was continually accelerated in the first half of the beat, was continually retarded in the second half of the beat, until it came to rest at the midship frame. There the return beat was supposed to be begun, and it was terminated at the stern. Now as a pendulum in swinging to and fro suffers no loss of power, except only that which it suffers from friction, it appeared to me that if each particle of water could be moved in the same manner as the ball of a pendulum moves, there would be no loss of power in thus moving the water, except what is lost in friction; and as the water could manifestly be so moved by giving a proper configuration to the sides of the ship, I saw no impediment to the construction of vessels upon these principles. Several such vessels were accordingly constructed by me, and I expected a

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superior performance from them. But on trial I found that, although they went with great smoothness through the water, and raised no apparent wave at any particular spot, yet that the speed they attained but little, if at all, exceeded that of ordinary vessels of good form. As, however, the water was certainly moved by these vessels in the manner of a pendulum, and surrendered the whole of its motion before it was finally dismissed at the stern, it was certain that the water could not go off with any of the mechanical power which the engine generated, except in so far as it was put into motion by friction; and it was plain, therefore, that it was to the friction of the bottom that the main part of the resistance must be ascribed. This doctrine is now generally accepted. In all vessels there will be a certain resistance caused by the difference of level between the bow and stern, and the amount of this difference can easily be determined when we know the sharpness of the lines and the speed of the ship, or, in other words, the velocity with which the water must be moved sideways to enable the vessel to pass. As a particle of water which is encountered by the stem has to move through half the breadth of the vessel in the time that the vessel moves through half her length, there must be a sufficient difference of level, or, in other words, a sufficient head, to impart this velocity of motion, and there must be an equal difference of level to carry the particle back in the necessary time to the stern. In very blunt vessels, pressed with a great power of engines and sails, the sideward motion of the water has to be so swift as to require a very high head to generate it, or, in other words, there is necessarily a great difference in the level of the water at the bow and stern, by which incident a serious amount of hydrostatic resistance is produced. But in steam and other modern vessels formed with the ordinary amount of sharpness, the amount of hydrostatic resistance is small; and it is reckoned that about nine-tenths of the total resistance is produced by the friction of the bottom. Unlike the friction of solids, the friction of fluids varies with the amount of rubbing surface, and may, therefore, be rather designated as adhesion. The form of cross-section will, consequently, influence the resistance; as, with any given displacement, and any given sharpness, some forms will involve a larger rubbing surface of the bottom than others. Thus a very broad and shallow river vessel suffers with any given displacement a very much greater resistance than a vessel with a semicircular midship section, in which form the amount of rubbing surface is the least possible. In fact, the resistance of a vessel of any given length is measurable pretty nearly by the immersed perimeter. A vessel, consequently, of twice the breadth and depth will have twice the length of immersed perimeter, and consequently twice the resistance from that cause; and if she is also made of twice the length, she will have an increase of resistance in consequence of the increased surface due to the increased length. But this resistance will not follow the same law as the other, especially in the case of long ships, seeing that the resistance of the hinder part will be reduced, from the circumstance of being floated by water which has already

been put into motion by the forward part. The law of decrease in the resistance per foot of additional length, however, is not known; nor can it at present be absolutely asserted what proportion of length to breadth will give a minimum resistance for every particular speed. The fact, however, that the sharpest vessels in our navy give better co-efficients at low speeds than at high, shews that those vessels are not sharp enough for the attainment of their highest rates of speed with the minimum of power. It would be easy to carry out some experiments to ascertain at what particular speed the best co-efficient is obtained. This will not be either at a very high speed or at a very low; and the particular speed at which the resulting co-efficient was found to be largest would fix with certainty the proper amount of sharpness for that particular speed and depth. If the speed be doubled, it does not follow that the sharpness should be exactly doubled, as the increase of friction, consequent upon the extension of the length, might more than balance the resistance due to the increased head requisite to give greater sideward velocity to the water. But it may be generally asserted that with every material increase in the speed, there should be a material increase in the sharpness, though it does not appear probable that the sharpening should proceed in exactly the same ratio as the acceleration. In the case of screw vessels, however, and also in the case of river vessels propelled by a paddle-wheel at the stern, since the propeller, by moving in the following current, recovers a portion of the power expended by rubbing the water into motion by the friction of the bottom, there will be less eventual loss resulting from an extension of the surface in the direction of the length than there will be in ordinary paddle vessels with the wheels at the sides, as side wheels do not rotate in the current which the ship creates.

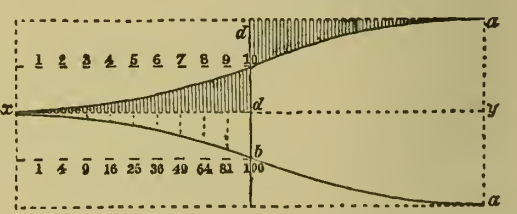
Thus much then is clear with regard to the proper form of ships: 1st. That the water lines should be such as to give to the water the same species of motion that is given by gravity to a pendulum; or the lines may be of any similar or equivalent form which involves the necessity of the water, before finally leaving the vessel, surrendering all the sideward motion which it had obtained. 2nd. That the proper sharpness for any particular speed is ascertainable by finding the particular speed by experiment at which the co-efficient of performance is a maximum. 3rd. That in the case of vessels with stern propellers, the sharpness proper for any increased speed will vary nearly as such increase, or, in other words, that a vessel intended to attain twice the speed of another, of which the co-efficient is a maximum, should be made nearly of twice the length. And 4th, That the cross-section should be brought as nearly to the form of a semicircle as is consistent with other necessary indications.

The second part of the problem of the right construction of ships so as to confer most strength with the least materials, resolves itself into such a strengthening of the

deck as will enable it to balance the bottom. All ships are weakest in the direction of their length, and they should be regarded as great hollow beams, of which the bottom is the lower flange or member, and the deck the upper: and just as the bottom is strengthened by keelsons and other longitudinal beams, so should the deck be strengthened in like manner by similar attachments. All iron ships should have an iron deck under the wooden one, and should also have a box-stringer running round the mouth of the ship. The scantlings of the frames and plates should, it is clear, diminish from the centre to the ends, in order that all parts of the structure may be equally strong, and proper iron pipe stanchions, which both push and pull, should as frequently as convenient connect the main deck with the bottom. The experiments made to determine the proper proportions for the Menai Bridge equally illustrate the proper proportions of ships; and those experiments clearly shew that most of the material should be collected in the top and bottom of the structure, or what answers to the deck and bottom of the ship.

To illustrate the manner in which the water-lines of a ship should be drawn to give to the water the same species of motion that is given to a pendulum by gravity, we may, for the sake of simplification, suppose the cross-section of the ship to be rectangular, and consequently that the water has merely to vibrate to and fro upon the sides to enable the body of the ship to pass. If, therefore, we cause a sheet of paper to travel vertically with a speed representing the speed of the ship, and if in front of this travelling paper we hang a pendulum of such a length that it will make one beat in the time in which the ship passes through half her length, then a paint-brush or pencil stuck in the pendulum bob will describe the proper water-line, since if the sides of the ship are formed thereto, each particle of water will manifestly be constrained to move in precisely the same way as the bob of a pendulum naturally moves by the action of gravity. The water-line may also be easily drawn by the aid of ordinates. Thus, suppose the line $x\,d$, Fig. 1, to present one-fourth of the length of the ship, and let it be divided into ten equal parts. As the water has to move in the same manner as a body falls by gravity—for we may suppose each particle of water to fall sideways—the successive ordinates must manifestly be of such lengths as to conform to the law of falling bodies. In other words, if, during the first advance of the vessel through one foot the water is moved sideways one inch, then during the second advance of a foot the water must move through the square of 2 or 4 inches; or if the length of the first ordinate be 1 inch, the length of

Fig. 1.

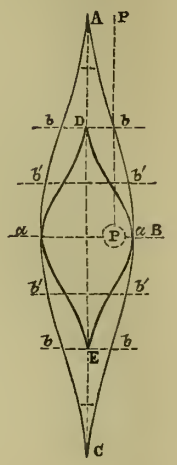


the second will be 4 inches, of the third 9 inches, of the fourth 16 inches, of the fifth 25 inches, and so on, increasing always as the square of the times which the numbers 1, 2, 3, 4, &c., represent, since those are the distances which the vessel passes through in equal intervals of time. In Fig. 1, *x y* represents half the length of the ship, and *a a* the midship frame. A particle of water encountering the stem at *x* must have its sideward velocity continually accelerated, if it is to fall sideways by gravity, until it reaches the point *b* midway between the stem and the middle of the ship; and as at *a* the particle has to be again in a state of rest, the velocity of the particle passing from *b* to *a* must be continually retarded according to the same law that is followed by a ball projected upward by gravity. The curved line *x b*, it is clear, must be precisely the same as the curved line *b a;* and instead of drawing the second curve by new ordinates, we may suppose the shaded portion, *x d*, to be cut out of the paper, and reversed so as to assume the appearance of the shaded portion *d a*. It is plain, moreover, that the area of the figure *x a* is equal to half that of its circumscribing parallelogram, from whence we may deduce the important law that the capacity or displacement of every ship of rectangular cross-section should be equal to half that of its circumscribing parallelopiped. Of course, ships seldom possess rectangular cross-sections. But it is easy to translate any other form of cross-section into a rectangular form by taking the area of each successive frame in the immersed portion of the actual ship, and by setting off the width on any rectangular design, with which any given depth will make the area of the corresponding frame in the rectangular ship the same as that in the real ship. By pursuing this course it will be found that the form of the water-lines will necessarily vary with the form of the cross-section, and that, whereas with a rectangular cross-section the water-lines of a properly formed ship will be necessarily hollow, with a circular cross-section they will become rounded, the area of each successive frame or cross-section remaining the same. Now it is not so much the form of water-line we have to consider as the *rate of displacement*, which will be determined by the areas of the successive frames; and if we fix the proper areas in the case of a vessel with a rectangular cross-section, as we can easily do by the method pointed out, then with any other form of cross-section we shall obtain the proper water-line by making the successive areas the same as before. It is a useful test of the proper form of any vessel to take out the areas of the successive frames, and to translate those areas into the rectangular form. If the curve connecting these areas is a regular one of the form represented in Fig. 1, then the shape of the vessel is good; but, if on the other hand, the curve is zigzag, jerky, or uneven, the shape of the vessel is bad.

In Fig. 2, A C is the ground plan of a ship of rectangular cross-section, of which *a a* is the midship frame, and *b b b b* the frames intermediate between the stem and the middle,

and the stern and the middle. P is a pendulum of such length as to make one beat in an arc extending from the middle line of the keel to the side at B in the time in which the vessel advances through half her length. The versed sine of this arc will represent the hydrostatic resistance as it represents the amount of head or fall requisite to give the necessary sideward velocity, whether to the pendulum or the water. With any given length of arc or half-breadth of the ship, it is plain the versed sine will increase as the pendulum is made shorter, or in other words, as the time of the beat is lessened, or the time is lessened during which the vessel passes through half her length. This is only tantamount to saying that, with any given length and breadth, the hydrostatic resistance increases with the speed. But if we simultaneously increase the length, then the length of the pendulum will remain as before, and the hydrostatic resistance will be unaltered. D B E is the ground plan of another vessel of rectangular cross-section of half the length of the foregoing. In this figure the breadths b^1 b^1 are the same as those b b in the larger figure and this would be the form suitable for half the speed.

FIG. 2.



ON CERTAIN CASES OF WEAKNESS IN IRON SHIPS.*

By E. J. Reed, Esq., Chief Constructor of the Navy, Vice-President.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Thomas Lloyd, Esq., Vice-President, in the Chair.]

The scientific construction of a ship involves all that is comprised in the construction of a fixed beam or girder, together with a mass of other facts and circumstances peculiar to the ship's own purposes and uses.

It is to Dr. Fairbairn that we chiefly owe the repeated enforcement of the fact that a ship is, in many respects, to be regarded in this way as a huge beam or girder, and it must be acknowledged that ships have repeatedly been placed in positions which, although exceptional, fully justify even the extreme examples with which he has illustrated his argument, by showing ships sometimes supported wholly at the middle and sometimes wholly suspended by the extremities.

A remarkable instance of the former occurred very recently on the Mersey, when an iron ship, laden with a cargo of iron, got across a stone causeway; and as an extraordinary case of suspension by the ends, I may mention that of the *Prince of Wales*, described by Mr. Clark in his work on the Britannia Bridge. The incident took place in the launching of the vessel at Blackwall, many years ago, at the works of Messrs. Miller and Ravenhill, and was considered, at the time, so demonstrative of the extraordinary strength of iron ships that Mr. Miller published an account of it. She was an iron boat 180 feet long, and, by the giving way of the bolts of the launching cleat, she was let down till the bilge bore on the wharf. She was ultimately forced off, cutting her way deeper into the concrete and planking of the wharf as she went, until she attained the position of having 110 feet between her bearing on the wharf and her point of contact with the surface of the water. Although the whole of the deck in the centre of the vessel was left unfastened for the reception of the machinery, it was found,

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when she was completely afloat, that her sheer was not broken, and that she had received no injury beyond that of the twisting of the bow by the set of the tide against the side. Three of the angle-iron frames were broken, and one of the plates cracked, the repair of these defects being effected in four days. Several cases of a similar kind occurred on the Mersey in the early days of iron shipbuilding; among others the *Nun*, a vessel of 65 horse-power, built by Messrs. Laird, which got aground on the end of a stone pier, and was there left by the ebb tide, resting by the stern on the pier and by the bow on a hard stone bottom. This vessel was 105 feet long, having in the centre an engine weighing 65 tons; and although she remained for many hours in this position, with a distance of 81 feet between the points of support, no visible deflection could be observed in the keel. It is unnecessary to multiply such examples, of which hundreds might probably be cited.

But a ship would obviously be most imperfectly constructed if designed as a beam or girder only, for she has to endure forces and to undergo deteriorating influences, to which a fixed beam or a bridge is not at all subjected. A ship has, of course, to be propelled through the sea either by the wind acting from without, or by steam generated within her; she has to be largely immersed in corrosive and vegetating salt water; she has to be lifted from the hollows of waves to their summits, and pitched thence into their hollows again; she has to endure being rolled violently through extreme angles; she has to undergo all this under the burden of weights often far greater than her own weight; and she has, in the mercantile marine, to withstand the deteriorating effects of cargoes that often tend greatly to injure and destroy her; while in the Royal Navy, she now is often expected to withstand not only the simultaneous discharge of several heavy guns, but also the shock of missiles weighing many hundredweights, propelled by enormous charges of powder, and containing explosive charges of considerable force. Besides all this, she is to be made capable of withstanding, as far as possible, all the trials of collisions, storms, groundings, and a multitude of other evils and mischances.

As it is my intention to give to my remarks here as practical a character as possible, I shall not enter into those general investigations respecting the nature and amount of the forces to which ships are liable to be subjected, and which have been very ably discussed by other persons. It will be sufficient for my purpose to bear in mind that a ship is substantially of the nature of a hollow beam or girder, narrowed away to nothing in breadth at the ends; that this beam is in a sea-way supported more or less by the ends and by the middle alternately, the supports shifting incessantly, and completely changing positions many times in a minute, thus throwing the top and bottom into states of both tension and compression successively. The strain of the masts and sails, and of the sea, tend to produce sudden and frequent changes of angle between

the decks and sides; and in cases of steamships, the thrust of the propelling shafts and the resistance of the water being exerted usually at different heights tend also to rack and strain the structure longitudinally. This outline of the subject will suffice to keep before our minds the nature and circumstances of the structure we have to consider, *viz.*, a ship's hull. Instead of seeking to fill up this outline by theoretical inquiries and expositions, I shall endeavour to do so by pointing out some of the weaknesses and defects which iron ships have practically been found to possess; because, however sound theoretical principles may be, the true requirements of a structure, subject to so many exigencies as the hull of a ship, cannot be thoroughly understood without a large resort to practical experience.

As the primary object to be kept in view in the construction of a fixed tubular girder is to adapt the top and bottom to receive the principal strains of tension or compression, as the case may be, the longitudinal strength of the upper and lower parts of a ship must obviously require to be very considerable. But as the construction of fixed girders was but very imperfectly understood prior to the building of the Britannia Bridge, and as the resemblance of a ship to such a structure is even now but partially understood or, to say the least, admitted, among shipbuilders, it is not surprising that both the upper parts and the bottoms of ships have been, in many cases, too weakly constructed.

I will, in the first place, instance the case of a large Atlantic mail paddle-steamer. This ship was not by any means deficient in the quantity of material put into her; on the contrary, the weight of iron in her hull was unusually great. But she was a very long ship, and after making a few passages across the Atlantic, it was found that she had not sufficient longitudinal strength to withstand properly the strains to which she was subjected. On examination, it was found that one of the plates and the strap over the adjacent butt, in the topside above the spar deck, in wake of the paddle-box, were broken, several of the rivets in the plating had worked loose in the neighbourhood of this fracture, and other slack rivets were found in the bottom plating under the engines and boilers, and in the hollow of the bows a certain amount of leakage resulting of course.

The manner in which additional strength was supplied in this case is shewn in Figs. 1 and 2.* An inch plate, *a*, Fig. 1, 2 feet 3 inches broad, was worked on the frames as a doubler to the $\frac{1}{2}$-inch strake immediately above the spar deck; and, above this, one $\frac{5}{8}$-inch and one $\frac{3}{4}$-inch plate, *b* and *c*, these plates completing the side up to the rail,

* In these and a few following figures the original plates of the ship are crossed to distinguish them from the plating afterwards added, which is drawn in solid black lines.

which was formed as a continuous $\frac{3}{4}$-inch plate *d*, connected to the uppermost strake by an angle iron. A second rail-plate, *e*, 15 inches broad, was worked a few inches below the upper rail, being let partly in between the frames to meet the outer plating; and below this, and connected to it by an angle iron, a $\frac{3}{4}$-inch plate, *f*, 18 inches broad, was worked on the inside of the frames, stiffened by an angle iron on its lower edge. This inner plate extended for a length of 103 feet, the outer plating for 112 feet, and the plate rails for 180 feet 6 inches, the ship being 374 feet long. This completed the strengthenings of what we may call the top of the girder. Below the spar deck a $\frac{3}{4}$-inch clamp, *g*, 2 feet broad, was worked for a length of 240 feet.

The bottom was strengthened by doubling the whole of the inner courses of plates up to the turn of the bilge for 50 feet in the wake of the engines, as shown in Fig. 2, thus making the bottom plating a flush surface at that part. The doubling plates are marked *h h*.

This mode of strengthening the bilge is one easy of application, and has been adopted in many cases by Messrs. Laird, of Birkenhead, who have had great experience in the actual indications of weakness in ocean-going steamships, owing in some degree to the circumstance of their works being easily accessible to vessels which have suffered from stress of weather in the Atlantic. In some vessels it has formed a part of their original design; in others it has been added where signs of weakness have become apparent after the vessels have been at work some time, and have gone to them for repair; and in others it has been adopted when vessels originally designed for general trade have been fitted out for carrying special cargoes of dead weight, such as machinery or telegraph cables, or have been lengthened in the midship body.

An example of the first may be found in the Holyhead mail boats *Ulster*, *Munster*, and *Connaught*, and in many of the long screw steamers now employed in the merchant service, trading from the port of Liverpool. The system is provided for in one of the Rules of the Liverpool Registry for Iron Vessels, when the length of the vessels exceeds certain proportions of breadth and depth. A specimen of this may be found in the steamship *Queen*, of 3,250 tons, recently built by Messrs. Laird for the National Steam Navigation Company.

In the cases of vessels which have been strengthened in this way, where weakness has become apparent after some amount of service, it has usually had the effect of preventing any extension of injury.

Among vessels altered for special service may be mentioned the *Imperador*, *Imperatriz*, and *Bahiana*, originally intended for the South American trade, but afterwards fitted for carrying the electric telegraph cable to the Red Sea, when very heavy

weights were placed in small sections of the vessel's length, and at a considerable distance before and abaft the centre of displacement.

The plates used are of the same thickness as the other parts of the outside plating, and care is taken to shift the butts of the doubling strake from the butts of the adjoining strakes. They extend from a half to two-thirds the length of the vessel. At each butt of the doubling strake there is a butt strap worked inside of the skin-plate, and the rivets pass through both. All the butts and seams are made close, and caulked tight, so that no moisture can get between the plates. Sometimes a layer of canvas, saturated with red lead, is placed between the surfaces; but often there is nothing but red lead paint, which does perfectly well if the plates are carefully fitted.

Another case which may be mentioned instructively is that of a large mail paddle-steamer built for ocean service, which encountered a gale in the English Channel on her first voyage out of port. On being taken into dock it was reported that the whole of the butts of the flat keel and bottom plating for about 180 feet amidships were much strained, and several of the butts in the upper strakes in the wake of the paddle-boxes and sponsons were likewise much strained, indicating such a deficiency of strength in the vessel, especially in the longitudinal direction, as to render her unseaworthy, and to fully account for the leakage which had taken place, and which was said to have required the whole of the engine pumps and bilge injections to keep it under. An experienced surveyor, who inspected this vessel on behalf of the owners, reported that, in his opinion, the structural weakness of this ship was so great that she could not proceed to sea without the risk of foundering, and that the following works would have to be done to fit her for sea. I give his suggestions in full, that it may be seen to what an extent this new ship was considered deficient in strength by this surveyor. He said: "Double the "upper strake with $\frac{5}{8}$-inch plate; rivet a box stringer 26 inches by 18 inches on the main "deck beams, made of $\frac{9}{16}$-inch plate, and $3\frac{1}{2}$-inch by $3\frac{1}{2}$-inch angle iron $\frac{9}{16}$-inch thick; "double a strake above and one below the bilge with $\frac{11}{16}$-inch plate; rivet upon the second "sunk strake from the keel a plate 18 inches by $\frac{11}{16}$ inches, and a double angle iron, 6 "inches by 4 inches by $\frac{5}{8}$ inch, riveted upon the middle of the 18-inch plate; plate over "the floors on each side the centre keelson for 24 inches with a double thickness of $\frac{1}{2}$-inch "plates; put in three additional rivets to the beam ends of the deck beams, 1 inch in "diameter; put into frames, where the plates are to be doubled, an additional rivet "(zigzagged from the present rivets) between them 1 inch in diameter; take off butt strips "in the flat and bilges and round the top strakes, from the present paint-cracked butt to the "aftermost paint-cracked butt, and re-rivet them; take off the rounded gunwale, and carry "the present beam ends out with a knee-plate to the frames run up straight; put on a "stringer plate, 3 feet by $\frac{5}{8}$ inch, doubled at the side, with a plate 18 inches by $\frac{9}{16}$ inch,

" both riveted to the top strake, carried up $\frac{5}{8}$ inch with angle iron 4 inches by 4 inches by " $\frac{6}{16}$ inch; deck to finish against 6 inches by 3-inch angle iron riveted on 18-inch plate; " butts of top-plate and stringer to be treble-riveted; bulwarks, $\frac{5}{16}$-inch thick, of plate " iron, to be carried round the vessel; rail of pitch pine, yellow-metalled, supported by " round stanchions $1\frac{1}{2}$ inches diameter;* topgallant forecastle to be carried up $\frac{7}{16}$ inch " thick; frames for forecastle, 5 inches by 3 inches by $\frac{1}{2}$ inch, carried down and scarphed " 3 feet; angle iron to carry rail double, 5 inches by 4 inches by $\frac{1}{2}$ inch. Riveting: all " the butts of the doubling strakes to be double riveted with 1 inch rivets; all the doubling " strakes to have inch rivets through the landings and spaces between the frames, " additional rivets in the bilge 1 inch, landings to be single-riveted, and rivets to be spaced " 6 inches apart between the frames, to be 1 inch; all the doubling plates to have a layer " of well-painted canvas between them and the ship plates." He concluded by saying: " I consider the ship at present well framed and plated, but not well riveted, nor well " arranged structurally to withstand the lateral or vertical strains she may be expected to " encounter."

I do not profess to fully comprehend the meaning of this approval of the framing and plating, combined with a condemnation of the structural arrangements of the vessel, and with demands for such large additions to the hull; but it is very obvious that the ship was far too weak, at least longitudinally, and that the weakness mainly exhibited itself at the top and the bottom.

The strengthenings which were actually applied to this ship before she was again sent out on service were as follows, and as shown in Figs. 3 and 4: An external iron keel, *a*, Fig. 3, made up of several thicknesses of plates, was applied and connected to the original flat keel by garboard plates, which, of course, served as doublers to the main flat keel; the plating of the bottom was made flush from this point to above the turn of the bilge over a length of about 240 feet by plates, *b b*, worked between the lapped edges of the outer overlapping plates of the bottom. An external bilge keel, *c*, was worked in the turn of the bilge, consisting of two plates on edge, connected to the bottom by two large angle bars. A large central box keelson, *d*, completed these lower strengthenings which involved an addition of more than 150 tons to the weight of the hull. Besides this, an increase of 15 tons was made to the orlop deck stringer; a stringer plate, *a*, and clamp, *b*, shown in Fig. 4 (on the main deck), was converted by an addition of 64 tons of plate and angle iron, *c*, into a box waterway or girder. In Fig. 4 is also shown the manner in which a double sheer strake, *d*, and stringer plate, *e*, weighing over 100 tons, were applied to what were before rounded beam ends, thus giving a new top, so to speak, to the ship herself, viewed as a girder. Other additions were made to the ship, in the form of bulkheads, bulwarks, a forecastle, &c., and much of the bottom was riveted

anew; but those above will suffice to indicate where this ship proved weak, and how she was strengthened by a very experienced firm.

Another case of a very similar kind, but presenting sufficient points of difference to justify a reference to it, occurred with a ship built for the same service. In the former case, no middle-line keelson above the floors was fitted in the ship originally. In the present case there was a keelson with intercostal plates below, between the floors, as shown in Fig. 5; but these intercostal plates were not riveted to the flat keel plates. There were also other differences in the original construction, the nature of which may be gathered from what follows. I should state here, however, that some of the longitudinal ties of this ship were broken at the bulkheads; some of the butt straps were considered of insufficient width to ensure good work; and some of the work itself was not of the highest class. The ship made a voyage or two across the Atlantic in safety, but she was found to strain considerably; and she was consequently taken into dock, and received the following repairs and additions which are illustrated in Fig. 6. The shell was re-riveted throughout, the projecting strakes of plating being nearly all taken off, and about half the sunken strakes, the countersinks of the rivets being enlarged, and the holes made fair. An external keel and doubling garboard strakes, *a*, were worked, as in the former case, throughout nearly the whole length of the ship. The box keelson was removed, and intercostal plates, *b*, were fitted and secured below, to the inner garboards, and at top, to the new bottom plate of the box keelson, *c*, which last was then put together again and re-riveted. The four sunken strakes of bottom and bilge on each side of the keel were doubled with plates, *d d*, of equal thickness for about 250 feet of length, the strake nearest the keel extending the whole length of the ship. The sunken strake near the main deck beams was also doubled by a plate *e*, for about 200 feet amidships, and a short doubling plate was worked under each paddle beam. A bilge keel, *f*, formed as in the previous case, was worked on the turn of the bilge. A box waterway or stringer, *g*, on the main deck was re-fitted, extended to the ends of the vessel, and secured on top to the outside plating by a plate and short angle irons between the frames, and a box stringer was fitted on the lower deck for about 240 feet of length. The sheer strake was doubled with a steel plate $\frac{1}{2}$ inch thick, and a stringer plate 3 feet wide by $\frac{5}{8}$ inch, riveted to the beams, and doubled by an 18-inch plate, secured to the sheer strake by steel angle irons, the deck finished on this stringer against steel angle irons forming a sunk waterway. A girder 2 feet 6 inches wide and $\frac{3}{4}$ inch thick, intended to aid in distributing the thrust of the paddle shaft, was wrought above the sheer strake and over the paddle beams.

Other additions were made, but need not be mentioned here.

From the foregoing illustrations it will be seen that the practical experience gained

with ships at sea shews the extreme necessity of giving great longitudinal strength to them, especially at the top and at the bottom. I do not consider that precisely the best means of securing that strength was taken in every case before described, but the object aimed at in each instance is apparent enough.

In endeavouring to secure the necessary longitudinal strength, either in building a new ship or in repairing a weak ship, one thing is obviously essential to an effective use of the iron applied, *viz.*, as near an approach to continuity of uniform strength as is possible. I have often been astonished at the extent to which this has been neglected in many iron ships that have come under my notice. It is, or certainly has been, a very common practice on the part of some builders to break their longitudinal strengthenings in a most remarkable manner. One common form of this defect is the practice of stopping short the longitudinal ties at a water-tight bulkhead, as in the case illustrated in Figs. 7 and 8. In building a certain ship, the central angle-iron keelson, marked *a*, was stopped short, as shown against the bulkhead B. The plating, *b*, forming the seat for the engines, and extending nearly to the turn of the bilge on the top of the floors, was likewise stopped short at the frame, F, no longitudinal tie existing originally between this plating and the keelson. To remedy this defect, which was discovered by a surveying officer, the builders afterwards applied the short scarphing keelson piece, *c*, formed of a plate between two angle irons, as shown in section at *e*, and carried water-tight through the bulkhead, and also the $\frac{3}{4}$ plate, *d*, 4 feet wide. The connexion between the plating at *b* and the keelson at *a* was thus effectually completed. A similar arrangement was carried out at the other engine-room bulkhead, where also the central keelson was broken off. In the same ship the side keelsons also were originally stopped at the engine-room bulkheads, and had to be strengthened in a similar manner, except that the plating, *d*, was not necessary, and the scarphing angle irons had no plate between them, but were fitted directly back to back.

In order to shew that this ship was not by any means an exceptional case, I will make brief reference to a few other examples of similar weakness, taken from reports of surveys with which I have had to do, or which I have had to consider. In one ship of somewhat recent construction, and built for ocean mail service, we found that the butts of the angle irons on the top of the centre keelson plate had no butt straps to connect them together, thereby considerably reducing and, in fact, almost destroying the value of the longitudinal strength of these angle irons. The gutter plates on the top of the floors, forming the flat central keelson, were found to be badly fitted, and several rivets in the short angle irons immediately under them were defective. The butt straps of these gutter plates were not made to completely cover the ends of the plates, thereby introducing a serious source of weakness. The butts of the angle irons and bulb irons

forming the side and bilge keelsons were not sufficiently connected together, and it was recommended to cover the butts of these angle irons with straps 24 inches long, and to introduce separate straps for the bulb irons. The bilge keelsons and lower deck stringers were found to be severed at some of the transverse bulkheads, and means had to be taken afterwards to preserve the continuity of their longitudinals. The main deck sheer strake, which was formed of two thicknesses, had butt straps to the butts in the inner thickness only, the butts in the outer being riveted to the inner thickness of plating. This, it will be observed, was very objectionable, as it, to a large extent, destroyed the usefulness of the outer thickness, and besides, with covers to one thickness only, the butts of the outer strakes should obviously have had them in preference to those of the inner, as it was the thicker of the two. To get the greatest strength, however, both the inner and outer thickness should, of course, have been supported with straps, as the increased thickness of plating forming the sheer strake was for the purpose of increasing the longitudinal strength of the sides, and, without straps, the extra plating used was merely adding weight to the vessel without obtaining the advantage aimed at.

I remember also another vessel, for the same service as the last named, in which the butts of the angle-irons forming the fore and aft bilge stringers were not sufficiently connected, requiring additional strapping in many places. Another example of the same defect was observed in a new ocean-going vessel. It was found that her main and side keelsons were stopped short at the fore and after part of the engines, completely destroying their longitudinal strength at these parts. They were afterwards made of continuous strength there, by the introduction of two deep angle irons riveted to each, carried water-tight through the bulkheads, and extended from 5 to 6 feet on each side.

But it is unnecessary to multiply instances of this kind, which are exceedingly numerous. It may be well, however, to state here that one very frequent source of longitudinal weakness in our ships—a more frequent source than would be supposed, probably—is the single-riveting of the butt straps. Out of twelve sea-going ships whose construction I was examining not long ago, no less than five were single-riveted at the butts of the bottom plating.

Having now practically illustrated as fully as appears necessary the great importance of securing longitudinal strength in iron ships, and especially at the top and bottom, I proceed to state that, when this has been sufficiently secured, there should be provided such intermediate strength of frames, clamps, beams, stringers, waterways, &c., as will insure rigidity throughout the skin plating of the ship under all circumstances. Flexibility in the skin is a source of great weakness and rapid deterioration, as I will shew by again referring to practical experience.

The first case I shall mention—and I intend to refer to but three—is that of a remarkably well-formed ship of about 1,200 tons. She had made her first voyage to India, and, upon her arrival in the Thames, the captain of her engaged a dry dock for the purpose of cleaning and painting her bottom. When docked, the owner, with the captain and her builder, marked forty-two rivets which leaked, and which were consequently cut and punched out. Fourteen of these rivets were at the junction of the fore bulkhead with the ship's sides. The rivets were carefully replaced; but when the water was let into the dock to float the ship, it was found that several of them at the bulkhead leaked. The ship was kept in dock, and every suspected rivet was taken out and replaced by new. A stream of water was then thrown upon the re-riveted parts with the force of a fire-engine—a device by means of which innumerable leaks in ships are discovered, every rivet being tested, and not one of them was found to "weep." The water was again let into the dock, and just as the ship floated several rivets started again, and with the new rivets two old rivets, which had not started before. The ship was retained in the dock, and the owner took the opportunity of securing the bulkhead to the skin more firmly by means of brackets. When the spring-tides returned, she was floated out of dock, took in a very heavy cargo at the Victoria Dock, and proceeded to sea. When near the Western Islands, she sprung a leak, and had to put back to Liverpool, where a survey was held upon her. The new rivets, with several others, had started, and the external plating was considerably torn in the way of the rivet-holes. The owner then brought an action against the firm who performed the new riveting work, and the matter was thoroughly sifted by a legal referee. The evidence adduced on both sides was of the most important character, and the fact was undoubtedly established that a want of rigidity in the skin of the vessel was the cause of the mischief. Instances were adduced of ships "panting" in their fore compartments; and it was proved beyond doubt that iron ships have in many cases expanded when dry on the blocks, and collapsed when sustained by the water. In this instance so strikingly was this the case, that the fore-bulkhead, which was perfectly tight when she was upon the blocks, buckled into an irregular curve when she was afloat. This ship now makes voyages satisfactorily, having had more rigidity imparted to her by an entire range of orlop-beams being put into her, with a stringer on each side at their ends, by some additional back irons, and by a double angle-iron with plates being added at the sides of her bulkheads.

The second case is that of a ship of 1,000 tons, built for the Bombay trade, and admirably constructed in every respect but one, *viz.*, insufficient beams and pillars. A ship rolling about with a heavy cargo will alter her form, as regards its tranverse section, very much, if she is built of iron, and is not sufficiently strutted and tied with

beams; for beams act, of course, both as struts and ties, according to circumstances. The captain of this ship on his passage out was much alarmed by a noise on board the ship, resembling the explosion of some combustible substance, and he concluded that a portion of the cargo was of this nature, and that the ship would be very soon in flames; no such result took place, however, but on arriving at India, and discharging his cargo, he found that some of the beams had been fractured and their pillars bent. The weight between decks was moderate, and, therefore, the accident could not be attributable to that. But the beam-end bracket plates appeared to have strained considerably, and the beams developed an error in their construction of an important description. Instead of being made of "bulb" iron, Fig. 9, they were made with two pieces of half-round iron at their lower edge, Fig. 10, so that when a violent strain was brought upon them they "buckled;" the half-round iron broke, and broke off the countersinks of its rivets, and the hole for the rivet became the commencement of a fracture across the beam, as shown in Fig. 11. The butts of this ship showed no indications of weakness whatever, and all that was done to her was to refasten the gusset-bracket plates at her beam ends, clamp the beams with a plate on each side, and introduce new pillars with a different mode of securing them, so that the lower deck and orlop beams should be compelled to yield together, if at all. One collateral circumstance may be referred to: the rivets in the garboard strake were in such a condition, from the alteration of the ballast and the action of the bilge-water upon their heads, that some were ordered out. It was found, however, that new ones could not be put in without disturbing the old, and the result was that all the butt-straps were removed, refitted, and entirely riveted anew. This wearing away of the rivet heads is a source of great injury to iron ships, and has led to the very general use of cement for their protection.

The third case is that of a ship which went into dock to be painted, but as the water was leaving her, it was observed that her plates appeared to be cracked in a way shown in Fig. 12. At about 20 feet from the stem, the projecting plate, *a*, the under or sunk plate, *b*, and the projecting plate, *c*, were evidently broken in two at the line, A B. Knowing that, with flexible ships, the edge of the bulkhead was a sort of node to the flexure, and that the rivets were very liable to become loose, the gentleman who told me of this case, asked the owner to accompany him to the larboard side, and there they found that precisely the same thing had taken place. There could be no doubt then that the bulkhead edge had to do with the mischief, and he asked the owner if he had done anything to secure the bulkhead to the ship's side. It turned out that some brackets had been put which no doubt relieved the rivets of the bulkhead frame, but they checked the bending of the plate, and it broke at the point where its flexure was stopped. The broken plates were cut out and replaced by new ones, stringers were added to the fore

body to give it rigidity, additional back irons were fitted to the frames, and a few additional beams introduced. Here again, are weakness and flexibility in the fore body, where iron shipbuilders and Lloyd's are supposed by some persons to put too much iron.

"To me it appears clear," says a practical man of great experience, in writing to me on the subject, "that rigidity of the skin of an iron ship is the most important "element of strength. It is impossible to see the broken frames and the odd bows and "sides which are occasionally brought under the notice of practical men, without coming "to this conclusion. Just imagine a ship's fore compartment full of a heavy cargo, and "contemplate (Fig. 13) the force with which it is lifted out of, and, immediately after-"wards, dashed into the water. What section near the neutral point in midships is "required to sustain a strain like that to which this compartment is subjected? It "appears to me that the section A, Fig. 14, forward is forced into the form shown by "the dotted lines, when the ship pitches, unless adequate beams and stringers are placed "in its vicinity to prevent it. On the other hand, when the end is thrown up, the skin "pressed upon by a heavy cargo has a tendency to expand, and mischief results in the "opposite direction." We must admit that there is much force in these remarks.

I will conclude these general illustrations of the strains practically brought upon iron ships by referring to two cases of ships grounding, and suffering injury from the strains thus brought upon them.

The first case is that of an ocean steamer which went on shore upon a sand bank at the entrance to a river, and broke across between the foremast and the funnel in the manner indicated by the Figs. 15 and 16, which shew the arrangement of side plating in the neighbourhood of the fractures on the port and starboard sides respectively. These figures cannot fail to suggest at once a source of longitudinal weakness, the mention of which I have reserved till now, for obvious reasons—*viz.*, the placing of the butts of the plating and other longitudinal ties in too close proximity to each other. A butt is usually (not always and necessarily, as I shall explain hereafter) a weak place, and it is of course essential to a uniformity of strength longitudinally that these weak places should not fall in or near the same vertical line or the same transverse section.

This important consideration was not attended to as thoroughly as was desirable in some of the earlier portions of the Conway and other tubular bridges, but I doubt if it was ever so completely disregarded as in the ship which is now under our notice. On the port side we have a butt of the second strake of plating, and a butt of the clamp behind it, both in the same frame space as the port, and close above it, and immediately over these butts of the outside plate and inside clamp, was a butt of the deck stringer plate. In the strake next below the port is a butt immediately under the port, and a butt of the

main deck stringer falls exactly in the same place. In the second strake below these falls another butt of the outer plating, in accordance with the common brick fashion arrangements of plating adopted in this and so many other ships; and close to the line of weakness formed by this astonishing succession of butts falling vertically above and below the port, the beam stringer of the hold was broken by the bulkhead at the fore part of the boiler room. It seems doubtful if the most evil ingenuity could have devised a worse or weaker disposition of material than is thus presented, and the strain of the ship on grounding naturally enough found out a weak place. On the starboard side also the fracturing force found for itself a somewhat similar place of weakness, and broke the side down through a butt of the deck stringer plate, a scuttle, a butt of outer plating, a butt of inner clamp, and through other butts below. It will be seen that the lower part of this fracture was diverted (by some cause not observable) away from the butts of the outer plating, and the hold beam stringer, and broke through two frames.

It will add to the interest of this case, if I state that I happen to be aware that the clamp between the upper and main decks and the main deck stringer were not in the vessel originally. The clamp was added afterwards, and at the same time the original stringer to the main deck, which had been cut considerably, was removed, and a new one substituted for it on that account. As this addition and this alteration were made expressly with the view of giving the vessel increased longitudinal strength, of which she was supposed to be deficient, it seems astonishing that in arranging the butts of the new work care should not have been taken to succour the weak parts, instead of placing them in exactly the same place as the existing butts, and consequently rendering the additional plates of the least possible service.

We often hear of iron ships being practically of one piece, while wooden ships are often spoken of as "bundles of sticks," but any one who will study this very instructive example will see, that unless a careful disposition of the butts of a ship's plating and stringers is made, it is quite easy to fall into arrangements which will justify the comparison of her hull to a series of short trunks, or tubes very imperfectly joined at their extremities, or to a hollow beam or girder, half broken through in several places before the strain it is to bear is put upon it.

The other case of a ship being injured by grounding which I have to refer to, is that of a ship of 1,500 tons, which got on shore across a stone causeway in a river where there is a great rise and fall of tide, and was left in that position by the tide. Her draught of water when taking the ground was 21 feet, and the breadth of the slip or causeway was 28 feet. She had on board at the time of the accident a cargo largely composed of iron, weighing about 2,100 tons. The weight of cargo and ship included was estimated at 3,180 tons. When on the slip-way her fore foot was a few inches in

the sand, but certainly not in any way supported by it, all the strain being in the middle of the vessel. I have had an opportunity of seeing a report upon this case, written by an experienced surveyor, who says:—

"The fractures to various parts will be hereafter enumerated; but it is worthy of "remark that during the time of her being on the ground, the pumps on the aft side of the "mainmast were forced up through the deck about 15 inches. The mainmast appeared "unchanged until she floated off, when it settled down, and the rigging became slack, "showing that the keelson had forced itself up into the heel of the mast, taking the iron "step with it; and when the vessel floated, the bottom dropped 5 inches to 7 inches, and "the mast followed. All the damage done to the outside plating was confined to the flat "of bottom and to the height of the upper part of bilges, and showing no strains in upper "works.

"I believe that in all cases of vessels being supported at their middle with their "ends free, as in this case, unless the base of support is of sufficient length, or the vessel "of very extreme dimensions, the bottom must crush up, and thereby prevent the great "amount of strain to the top that would otherwise take place; and I am disposed to think "that sand is the worst description of ground for a ship to set on, as it forms a curved "base, caused by the sharp ends of vessels settling in it, and, by not yielding in the middle, "communicates the strain to top, and the breaking must of necessity take place at the "sheer strake, deck stringer, &c., unless the bottom is of a very weak construction.

"It is evident from this damage that, had the ship double the amount of stringer, "and any quantity of strength given to the upper works over and above that at present in "her, the damage would have been the same, so that there can be no doubt about the upper "part of such vessels being sufficiently strong for all practical purposes. Again, the base "of support being only 28 feet, it is really surprising that the floors in wake of the same did "not crack or bend as well as break down, and that the vessel ever floated off, and that the "bottom did not break into a hole."

This case of damage is certainly very interesting and instructive.

The writer of the foregoing remarks considered that it was a favourable illustration of the merits of Lloyd's Rules, as no defect resulted, in his opinion, from imperfect construction. The following are the detailed injuries which were consequent upon the grounding:—

"*Keel* found to have bent, and up about 10 inches, but did not break; 44 feet will "be renewed. *Floor-plates.*—Thirty-four found broken. They were butted long and "short arms, and the alternate ones split down, as in Fig. 17. Again, alternately, the

" butts opened, and the rivets sheared off. Not one of the butt straps split, nor are the " floors split in wake of the rivet holes. *Frames.*—Thirteen on the port side and nine on " the starboard side found broken; thirty-five reverse frames broken at the top, parts of " broken floors; some butt straps to reverse angle-irons at the upper part of bilges and " below orlop beams broken in two. *Intercostal angle-irons* found bent up and broken " near the mainmast. *Box keelson plates.*—One plate of box keelson broken (the cover " or top plate), and it parted opposite a butt of side plate; all the side plates of keelson " have their butt straps on the inside of box, and therefore extend the whole depth. The " strap, like that of the floors, did not split down, but the rivets sheared off. Four plates " of keelson will have to be renewed, partly by the damage done to butt holes. *Outside* " *plates.*—Three garboard plates will require renewal, being very badly bent and cracked " in holes; others taken off and set fair; fifteen plates in bottom and bilges to be renewed " from the same cause; all the other plates to set fair and go on again. The above is " nearly all that will be required, except refitting where disturbed for getting the new " work in place, with some two or three beams and some other matters of little " moment."

The details of the bending and fractures resulting from the grounding of this ship are shown in Figs. 18, 19, and 20, from which it will be seen that the butts again proved, as was to be expected, the weakest points. I will only add, in this case, that I concur in the tribute of praise which the writer claims for Lloyd's Rules, in conformity with which this ship was fortunately built, and consequently exhibited no such defects as the former vessel; but at the same time it appears pretty evident, that the effects of the local upward pressure upon the keel in this case, were aggravated by the absence of an intercostal middle-line keelson plate. This, however, is no reflection whatever upon Lloyd's, because their Rules are very favourable to the use of such keelsons with bar keels.

ON THE DEPTH OF SHIPS.*

By E. Flachat, Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Thomas Lloyd, Esq., Vice-President, in the Chair.]

It is not without hesitation, that I venture to address to a meeting of gentlemen, eminent both for their science and experience, the following observations on the depth of ships.

The conclusions at which I have arrived do not agree with the ordinary traditions of naval construction. I designedly make use of the term *traditions* instead of *rules*, because, notwithstanding persevering search, I have been unable to find in any treatise, memoir, or paper whatever any law or principle for the determination of the depth, in relation to the other dimensions, of a ship. Now in the conditions both of tension and compression caused by change of form, depth is the most important element of rigidity which a ship, considered as a girder, can present, to counteract changes of form in a vertical direction. The breadth has the same effect on horizontal bending strains. The advantages of depth, viewed in relation to the structural strength of the hull, are so marked, that it is worth while to see how far it may be increased without the vessel's losing its good qualities as a ship. Depth has also another advantage, that of raising the deck well above the water level. It is by carrying away projecting features on the deck, and by tearing off the hatches or coverings of openings left for passage or ventilation, that the sea finds its way inside a ship, putting out the engine fires and endangering her flotation. The higher the ship is, the less the deck is exposed to be swamped by shipping seas. There are two things which save the deck from destruction: the first, that it is in general only the crest of the wave which gets inboard, and that thus the quantity of water which is shipped varies inversely with the height of the deck above water; secondly, and it is this which has the greatest effect in keeping the ship free, there is the tendency of the ship to rise to the waves, and this tendency is in an inverse ratio to its heaviness. I call the heaviness of a ship its weight divided by its

* Received March 11th, 1867.

volume. Now the way to diminish the heaviness of a ship is to increase the ratio of its volume to its weight.

If a ship's displacement be 1,000 cubic metres forward, and 1,000 aft, and its volume be 4,000 cubic metres, of which 2,000 only are immersed, a sea, which can come on board, must exert, in lifting the ship, before it can do so, an effort which will vary directly as this height, until it shall have reached the limit of complete immersion of the ship. At that moment the effort of immersion will be equal to 2,000,000 kilogrammes, multiplied by the height of the wave which floods the ship, measured from the load-water line, and then the ship will emerge with considerable violence. This leads to the inference that the height of ships out of the water tends to diminish the danger of shipping a sea, and may even go so far as to get rid of this risk completely. It remains to be seen whether freeboard (that is to say, the depth of a ship) can be increased without diminishing its nautical qualities.

The quality of a ship which takes precedence of all others is stability. Does this depend on the height of a ship out of water? The stability of a ship depends on certain relations of the form and dimensions of the immersed portion of the hull, and on the situation of its centre of gravity. Stability of form is not unfrequently distinguished from stability of weight; but in reality these two sources of stability are inseparable, seeing that they form the two parts of a couple which tends to right the ship against any couple applied to upset it, or make it heel. The effect of heeling is generally to increase the surface of the water-section, and invariably to raise the centre of weight, so that the heeling tendency is always more or less counteracted by the tendency of the action of gravity to bring the centres of figure and of weight into the same vertical line. In the calculations of stability, the form and dimensions of the hull are only of importance, so far as they are, or may become, immersed. In so far as any portion of the topside, which is out of reach of immersion, has no effect, either statical or dynamical, on the centre of gravity, it does not affect the stability. In other words, if the part of the ship, which is always out of water, and remains so at the greatest angles of inclination, had no weight, its form and its height would have no influence on the behaviour of the vessel. It is, therefore, only the relative weight of the upper works, and its dynamical action, that need be considered. I propose to simplify the treatment of the question by confining myself to examining it with reference to the requirements of Transatlantic packets.

The Transatlantic steampacket is a vessel built for steaming at all draughts from light to load. At first, that is to say, at its launching draught, and later, when its engine is on board, but no coals or cargo, its centres of weight and of figure must lie exactly in one and the same vertical line; and this property must hold throughout all

its variations of lading, both with coal and cargo. Stability is just as necessary to it at its light, as at its load, immersion. The vessel must be in equilibrium in both conditions, to this extent, that the weights and their moments, taken with reference both to the centre of weight and to the centre of volume, situated on the same vertical line, should be equal, or should approach as nearly as possible to equality.

The addition to the light displacement of the coal and merchantable cargo should produce no change in the nautical properties, except an increase of immersion; and if the vessel is well constructed, that will not produce any marked effect on its periodic time of rolling or pitching. Lightening the draught tends to diminish the righting couple, owing to the rise of the centre of gravity due to the consumption of coal, and the increase of the moments of the top weights tends to increase the amplitude and duration of the rolling period,—but these effects are restricted within narrow limits if the ship has been well designed.

Within the belt comprised between the light and load lines due to the consumption of coal on the passage, apart from cargo, the water-line is practically unaltered in form amidships, and undergoes no serious variation forward or aft, and thus the moment of inertia of the plane of flotation undergoes no marked change. It undoubtedly happens sometimes that a vessel has not sufficient stability of form; that is to say, that the surface and moment of inertia of the water section diminish too rapidly as the vessel lightens, and that the centre of gravity rises. If then the vessel heels, it takes a permanent list, whether the heeling may have been due to the effect of wind or to some slight inequality of lading, or whether the rise of the centre of gravity may have produced indifferent equilibrium, with reference to its weights; but this is a defect of design easily remedied, for the stability may be measured, at all stages of immersion, like a weight in the scales. In the present day an error in the stability of a ship is unpardonable on the part of the designer; but we must still expect that for a very long time the want of instruction of mariners will endanger the stability of merchantmen by bad distribution of the cargo.

The Transatlantic packet differs notably from the freight-carrier, because its light and load displacements differ but little. The weight of coal and cargo together make up but one-third or one-quarter of the displacement. Moreover, the spaces in which these weights are to be placed are settled beforehand, and their influence on the rolling and pitching can be completely measured. There need therefore be no error; and we may say, that, with regard to its qualities as a sea-boat, a Transatlantic packet ought to have no element left uncertain; for the mathematical conditions of its design are absolute and simple, inasmuch as all the formulæ on which they depend are directly reducible to equations of form, of weight, and of moments.

Nevertheless, if a practice has arisen by virtue of which vessels are built so as to incur risk of destruction at sea for want of sufficient freeboard, there must be some reasonable cause for this practice. It cannot be assumed that the reasons why vessels are usually low in the water are particular to each ship. For some of them, doubtless, one reason may be the objection to receive the whole force of a wave against the bow, and another, the effect of the wind on the hull. Even so, the first object is doubtful. It is difficult to determine whether more work is lost in steaming ahead with part of the deck under water, or in rising to the wave and cutting through its ridge. At any rate, these considerations do not apply to Transatlantic packets. For these vessels it is important that the deck should be kept as comfortable as possible, especially in rough weather, when the passengers suffer most below. Now this involves two postulates—easy rolling and a high deck. These two conditions, far from being contradictory, agree, for this reason, that the moment of the topweight increases the period of rolling, at the same time that it diminishes its amplitude. We are thus led to assume that the want of depth in ships is due to the traditions of wooden shipbuilding. It is a consequence of the use of timber that its scantling, and consequently its weight in the topsides and upper decks, differs but little from the scantling and weight of the immersed portion of the hull, and this consideration assigns a limit to the ratio of freeboard to draught. Without some such limiting ratio, if the topsides were too heavy for the under-water works, it would be necessary to ballast the ship before launching her. This consideration explains all the peculiarities of wood-built ships. It accounts for the variation of breadth of beam in ships of war, which depends on the number and height of the fighting decks. It accounts equally for the low freeboard of merchantmen, which, in case of their finding no cargo at their ports of call, would be obliged to ballast heavily, if their topsides were out of proportion to their light displacement.

But this motive, which, in wooden shipbuilding, so emphatically limits the depth of ships, has far less importance when the ship is iron built. It is much easier to obtain the requisite strength in iron than in wood, and this strength increases with the better quality of the iron. It is easier to obtain a rigid truss with wrought iron than with cast iron, and with steel than with wrought iron, so that we may obtain the same strengths with less weights, by using the stronger materials. Now if this be true as a general axiom, it holds *à fortiori* when the resisting material can be distributed over the structure, so as exactly to meet the distribution of the forces both in direction and in amount. Of this character is the girder, whose material is chiefly massed at top and bottom, because the central portion has but little work to do. So also is the hollow pillar: its material being arranged so as to increase the diameter, increases the ratio of breadth to length, and thus allows a heavier weight to be borne at the same height, or

an equal weight at a greater height. In designing the upper works of a ship, it is easy so to contrive the distribution of material as to obtain the greatest possible strength of structure as a whole, and, seeing that the height enters by its square into the formulæ of resistance, the weight of the upper works will admit of a diminution, not in a direct ratio to the increase of height, but in a certain relation to it, as the depth increases. These remarks show that the depth of iron ships, and consequently their freeboard, might be much increased, without any proportional increase in the weight of the upper works, and without any change in the form of displacement.

Finally, we may conclude that the depth of ships, as regards freeboard, is in general insufficient, as it exposes the deck too much to the sea; that as regards structural strength, the increase of depth is advantageous; that as regards ease in a sea-way, increased freeboard is an element of comfort and safety; that by the use of iron in construction, the depth can be increased without interfering with the sailing qualities or speed of the ship, because it affects the weights only, or rather the positions of the weights in relation to the form of the ship, without affecting the form; and, lastly, that the insufficient depth generally given to ships is due to the traditions of wooden ship-building.

ON THE SPECIALITY AND CLASSIFICATION OF SHIPS OF WAR.*

By Vice-Admiral George Elliot, Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Thomas Lloyd, Esq., Vice-President, in the Chair.]

In all times past, the navies of the world have consisted of different classes of ships, intended for special services, and each class of vessel has had its own peculiar requirements, and so far was credit due to the designer as he succeeded in excelling in those qualifications which rendered a war ship the most efficient of her class.

The line-of-battle ship, the frigate, the corvette, the gunboat, the floating battery, the mortar vessel, each name represented a class of vessel, possessing peculiar and necessary qualifications, and the naval architect, when he was informed what class of vessel he was required to design, knew at once the elements of success which it became his duty to compete for.

It may be said that ships formerly were classed according to size or tonnage, and this was in a great measure the case. But it so happened that as the number of decks was reduced, lighter draught and greater speed were obtained, so that the frigate was of less tonnage, but outsailed the line-of-battle ship, and the corvette was still smaller than the frigate, and yet often beat her in speed; and the brig and schooner could compete with all larger vessels, and thus the weakly armed vessels had the means of escape from capture.

This law of safety is one which common sense would point out as too important to be disregarded.

But steam power and armour plating have created a new order of things as regards the means of obtaining great speed and light draught of water; and whilst the heavily armed frigate with great speed must be larger than the line-of-battle ship, she will be unsuited from her great length to take station in the line of battle, and for

* Received 30th April, 1867.

smaller vessels of light draught and great speed, armour plating must be dispensed with altogether.

Yet it would appear that, since armour plating has been considered a necessary defensive element of war ships, the naval world had entirely lost sight of former requirements, or as if the new feature of plating ships' sides had brought with it a change in the character of future naval warfare.

There is certainly a deviation in point of size in the thirty-four armour-clad ships which have been produced, but we have lost sight of classification altogether; and in the ships we possess, that law of safety which regulated the speed of ships, so that the weaker vessels could escape from capture, has been disregarded, or in fact reversed, for the *speed* is diminished *pro rata* with the decrease of fighting power, so that the weaker vessels must become an easy prey to the first heavier armed ship they meet, and if a naval war broke out to-morrow, the main feature of strength upon which we have always depended—*viz.*, a line-of-battle fleet—is nowhere to be found, nor the frigate, nor the corvette. I mean that we possess no heavily armed armour-clad ships which, without constant use of steam, could, when formed into a fleet, be kept together in compact order as a cruising fleet; and I presume that it will be admitted that compact fleets will be required as heretofore, and to the efficiency of that fleet will still depend the mastery of the seas; and I also presume that it will be admitted that it is not intended that the line-of-battle fleet will be navigated under steam, but that its normal condition for cruising purposes will be under canvas alone.

Amongst the ships we possess, there is a nearer approach to be found to the future frigate type, but still that essential element of *seaworthiness* is, I fear, nowhere to be found, even supposing that the steam power is always available, which cannot be expected; and I maintain that we have sacrificed this most essential element for sea-going ships to an unnecessary and dangerous extent.

It may be said that no other nation is better off; but that is no reason why we should follow in the wrong path; and besides, other nations have not the same sea-going requirements for their fleet which this country must always have.

I consider that armour plating has in no way reduced the importance of classification of ships or of their safety at sea; and I maintain that, had we continued to build ships for special services, there is nothing in the new feature of armour plating which has prevented each class of ship from being as perfect as of old to fulfil the services required of them.

I do not blame the naval architect for this want of efficiency in our fleet: it is not his duty to point out what war ships have to do, or how they have to fight, or what

guns they should carry—that is the duty of the naval officers the advisers of the Crown; and if the naval architect had been clearly informed what special points of merit he had to provide for, and on what points a sacrifice might be admitted, he would have provided the nation with a type of line-of-battle ship, excelling chiefly in fighting powers, of a moderate speed, capable of cruising in the line under sail alone, and of weathering the heaviest gales without the use of steam; and he would also have provided a type of frigate of great speed and seaworthy, although of greater length than the line-of-battle ship, and therefore *not* suited for the line of battle, and also with a class of corvette without armour, of a higher speed than any that we yet possess.

As it is, the naval architect has been called upon to make every vessel excel upon all points, and in trying to do this he has failed to excel on any; and we find that they are all of them most dangerously deficient as sea-boats, and none of them suited to form a line-of-battle fleet for sea-going purposes.* Now the excuse which is always made for this is, that we are in a transition state! I cannot say how tired I am of that excuse, which in my opinion is one which never should be heard, because have we not always been, and shall we not always be, equally subject to the laws of human discovery and invention? And so far as these discoveries have affected the naval architect in preparing designs of ships, it has been in reality a mere matter of weight and corresponding dimensions; and in this respect the same laws have always been in force, and I see no reason whatever why the iron clads should not be as good sea-boats as those of old, provided you do not attempt to combine in the same vessel great fighting power, great speed, and shallow draught of water, and then expect to produce a manageable vessel.

With a certain sacrifice of speed and with a certain increased draught of water, a fighting ship can be obtained of the line-of-battle class with iron sides; and in the same manner, by other conditions of sacrifice, a ship qualified to perform the duties of a frigate can readily be supplied.

I will now endeavour to describe more particularly by a diagram which I am pointing to, in what manner I consider the naval architect should be dealt with, and in what respect he should be responsible on the one side, and the naval officer on the other, for the efficiency of the fleet of this country. The diagram represents in numerical order of importance, the qualifications which the naval architect should give to each class of war vessel.†

* At present I really believe that a gale of wind would almost cause as much damage to the fleet as a naval action.

† On the naval officer must rest the responsibility for the order of merit contained in that diagram, and on some points he must fairly be expected to give a more detailed expression of opinion, after which the naval architect should be responsible for the skill displayed in combining these conditions to the best advantage.

It will be seen that I have placed sea-going first, in all three classes; and I am ready to support that opinion upon the grounds that, in the first place, it is due to the officers and men, who have to contend against a dangerous element, that they should have confidence in the ship they belong to, that she possesses in her construction the elements of safety; and, in the second place, it is most important in an economical and service point of view, that your fleet should not be damaged by every passing gale.

Then in the liner, I place turning second, because it is an element of safety in a fleet, and an element of fighting, as well as a means of keeping a fleet in compact order. Having ensured that the liner is a sea-boat, and capable of taking station in the line, I then make her the standard of the best fighting power, that is the heaviest metal the Ordnance Department can produce, and the thickest side a ship can carry consistently with those qualities which were first required. Then I place sailing number 4. Now although in this respect I would not require of a steam ship the same complete rig and amount of canvas which, as sailing ships, they would have possessed, yet I would give them sailing power sufficient to ensure their being perfectly under command as cruising ships.

Classification of Ships of War and Qualifications of each Class in numerical order.

Liner.	Frigate.	Corvette.
1 Sea-going.	1 Sea-going.	1 Sea-going.
2 Turning.	2 Steaming.	2 Steaming.
3 Fighting.	3 Fighting.	3 Stowage.
4 Sailing.	4 Stowage.	4 Draught.
5 Steaming.	5 Sailing.	5 Sailing.
6 Stowage.	6 Turning.	6 Turning.
7 Draught.	7 Draught.	7 Fighting.

Steaming comes number 5, and then the stowage, and last draught of water.

Now the naval architect has a perfect right to ask for definite instructions:—First, as to weight of guns and armour, and the space to be protected; and second, as to the number of knots; and third, as to the number of feet of draught of water; and fourth, as to the number of days' fuel and provisions; and on these points the naval officer must be responsible, and give the required information. My reply to these questions would be, for a liner—First, a side of the *Hercules* type, making all through a foot of iron, a twelve feet belt, and two turrets with base protected, carrying two of the heaviest guns in each, and a certain number of heavy guns unprotected; second, eleven knots at the measured

mile; third, twenty-seven feet the extreme limits, which on an even keel would afford, I think, sufficient displacement with a short ship; fourth, coals at least a fortnight at full speed, and provisions three months, and water for one week.

Now I beg to say, that I have not studied these points sufficiently, but I don't think I should have much to alter on fuller consideration. My object has been rather to shew what I mean, by qualifications in numerical order.

Armour plating and heavy artillery have rendered two and three tiers of guns no longer expedient, therefore the line-of-battle ship must be limited to one fighting deck; but this class of our fleet must be designed especially for fighting purposes, and the sacrifice of speed and draught of water must be submitted to, so as to combine this fighting power with those elements essential to making her a handy ship in action and a good sea-boat under canvas.

It may be said that speed is a valuable element in a line-of-battle fleet, and I may be asked how I am to catch an enemy's fleet if they should run away. My reply is—if the enemy's fleet has more speed, it can only obtain it by a sacrifice of fighting qualities of some kind. If he runs away, he at once leaves me master of the seas—Rule, Britannia! But I have a means of stopping him. I let loose a few fast heavily-armed frigates, and they will retard the progress of the slowest ships of the enemy, or bring on a frigate action; and, once some blows are struck, I may hope for a general action. Besides, there will always be an unavoidable margin of speed in ships of the same class, and my fastest liners will be sure to catch his slowest, and thus bring on an action, and then my fighting powers will tell in victory; and of what advantage to him will it prove that he had made speed stand in the way of fighting quality, by doing which he lost his fleet? No, give me the fighting fleet of the line, and I should be contented with 10-knot speed, which, I suppose, means 11 knots at the measured mile.

It is on this class of our fleet that we depend for our safety as a nation.

In a compact body this line-of-battle fleet must cruise under sail, and encounter all weathers, and win the day of battle when it comes.

That is truly the mastery of the seas; and I put it to naval architects,—whether there is anything in armour plating and heavy guns to prevent this type of war ship from being obtained.

I know the great difficulty of regulating weights so as to secure easy motion.

In a deep ship the engines are low, and the leverage, therefore, great, and the armour belt below the water line; but the whole weight of armour and guns has been placed on the sides of the vessel, and great weight placed in the extreme bow and stern,

and thus all the elements of uneasy motion have been intensified, so that no amount of skilful designing could produce an easy ship.

But I do maintain that we have neglected, to a great extent, the importance of adopting all remedial measures to reduce, as far as possible, the causes of violent and extensive rolling and pitching.

The great object to be obtained to procure easy motion is to concentrate as much as possible all weights not only vertically towards the water-line, but also from the sides to the central line, and also from the bow and stern towards the centre.

The broadside principle is antagonistic to this.

The bow and stern batteries are a part of this principle, and are fatal to the sea-going qualities of a ship, therefore the neglect of taking advantage of the turret principle has been a fatal error.

To raise the weight of engine considerably towards the water-line, and to get rid of the great weight at the stern, which the screw propeller necessitates, would remove all difficulty from the work of the naval architect; and I am glad to say that this advantage is now within his reach by the adoption of the hydraulic propeller.

And yet we hesitate, with such advantages within our grasp. And there is far more to be gained than that by this new propeller. Yet it appears that, like the turret principle, it may have to stem the tide of prejudice for a lengthened period, except that I have great faith in the clear-sightedness and impartiality of the present Board of Admiralty.

I have mentioned the hydraulic propeller as affording the means of facilitating to almost any extent the most advantageous distribution of weights, by raising the engines to any height required, and by dispensing with the great overhanging stern weights required by the screw propeller.* And I would also call attention to other important advantages of the hydraulic, as contributing towards a steady platform. The turbine itself is a central weight, and from the great centrifugal force exerted it will produce a certain amount of counteracting power to the rolling of a ship. And really it is a most serious defect, that ships should roll about, as our present ships do, especially when sails are furled; and what an unfortunate effect it would have upon the efficiency of a fleet when moving about in action regardless of the direction of the swell. And in heavy weather, I really do not believe that any spars or sails would stand the test of such heavy rolling, and if

* There is no reason why the turbine should not be close up to the water-line. In fact, it is advantageous to the propeller that it should be there.

that means of steadiment is gone, there is nothing for it but to bow the sea with steam power, and if that fails and the dismasted hull is left to its own momentum, such a case was bad enough in olden times, but what would it be now? and naval actions generally leave ships dismasted.

Then surely we should grasp at every means of so regulating the weights, that the easiest motion may be secured; and the hydraulic, in this respect, will prove your best friend.

And also, in many other ways, ought this principle to command the attention of naval architects. If the water is discharged at the water-line, the impediment to the speed of a ship under sail will be very slight as compared with the screw, which, if not raised, is always a drag in the water, in addition to its retarding effect by increasing the sending and pitching of a ship in a sea-way.

And, as the hydraulic has now proved itself equal to the screw at the measured mile, by the speed obtained for the same power in similar vessels, it must be placed at great advantage when a ship is pitching, and the screw is making repeated visits into the air; and surely this must prove a source of economy of fuel in long voyages, both when sailing and steaming. When the screw is superseded, the naval architect will rejoice to find himself unembarrassed in designing a sailing ship, both as to the form of vessel and as to the position of weights; and I believe that the nation at large may rejoice to see in the dawn of this new motive power a revival of her maritime superiority, because it admits of a return to a more perfect construction of sailing vessels, when good seamen will again become an essential feature of the strength of our sea-girt isles.

Again, the hydraulic propeller causes no vibration, so that a great cause of discomfort is removed, and the weight and expense of strengthening a vessel to withstand the vibration of the screw is avoided.

Again, the hydraulic propeller will prove itself most valuable in reducing the danger of collision, as the officer in charge of the deck will have the power of stopping the ship in twice or thrice her own length from full speed, by reversing the nozzle valves, and this power is under his immediate command, without any orders to the engine room; and many a man's life, and much valuable property, will be saved by this facility of not only stopping, but returning to the spot where the man fell without turning the vessel round. Because I consider that all new vessels with the hydraulic propeller will be shaped alike at both ends, and thus obtain equal speed both ways; and this feature is invaluable to war ships, by doubling the destructive power of ramming, which, I am convinced, will become the great element of sea fighting.

To exemplify what I have said, I will give an instance of what has quite lately occurred. A vessel called the *Mary*, whilst in the act of sounding, found herself in shoal water on the edge of a bank. Owing to the orders conveyed to the engine room having been mistaken, she was carried further on, and before the mistake was rectified, she struck the bank two or three times heavily abaft, and the first time she struck, the starboard screw and end of shaft broke off and disappeared at once. The vessel had no other damage done to her hull. The *Mary* was the property of the Messrs. Dudgeon.

Now, with the hydraulic propeller nothing of this kind would have occurred; as no orders are required to the engine room, the directing power of the engines being under immediate control on deck; and in case of a ship striking the ground, whilst the screw is always subject to damage, the hydraulic is safe.

Again, the hydraulic engine, acting as an enormous pump, will discharge from the hold upwards of two tons a minute per nominal horse power; so that, with an engine of 500 horse-power nominal, 1,000 tons of water a minute will be discharged in case of shot holes or a leak admitting the water, and there is no possibility of choking so large a discharge pipe. Thus we may anticipate that many vessels may be saved from foundering, many lives will be preserved, and many wrecks and collisions avoided.

Again, the hydraulic propeller can never be *fouled*, whilst the screw is easily disabled by floating obstructions in the water, and, as the nozzle can be protected by a shield, or placed under water out of harm's way in action, the motive power is always safe, whilst the screw and stern-post must be to a certain extent exposed.

Now, on the question of speed, and as proof of the success of the hydraulic propeller, I am justified, from letters I have received from Mr. Dudgeon, and from the results of the Admiralty report of the trials of the *Waterwitch*, in stating that substantial evidence on this point has been obtained.

I conclude it is well known that the *Waterwitch*, fitted with the hydraulic propeller, is a sister vessel to the *Vixen* and *Viper*, perfectly new, armour-plated twin-screw gun boats, designed by the Comptroller of the Navy. These three vessels, of about 750 tons and 160 horse-power, being nearly alike in all respects, except in the character of the propeller, afford a very good test of the merits of this new motive power.

The result of trials, which have been made at the measured mile by these vessels, have proved favourable to the hydraulic propeller, as contained in the reports of trial I have received from the Admiralty, and further trials are about to be made by actual competition at sea between these vessels. And by a further comparison between the *Waterwitch* results of trial, and those of two armour-clad vessels of the same type,

called the *Medusa* and *Triton*, built by Messrs. Dudgeon for the Brazilian Government, it appears that the hydraulic propeller has also in that instance shown equally good results; and these vessels were fitted on Messrs. Dudgeon's most improved twin-screw principle. Mr. John Dudgeon is, I believe, present; but he has authorised me to say that he has gone carefully into the matter, and that he considers the hydraulic has shown itself equal to his best twin-screw principle.

It is true he constructed the engine of the *Waterwitch*, but he is known as the special friend and the most successful designer of twin-screw vessels, and I believe his vessels have equalled the best speed of the single-screw or paddle. And I consider it most fortunate to have obtained the advantage of his ability and generous support in developing this new motive power, and that his opinion is devoid of all prejudice.

I will not go into details, for there is not time, but so far as these trials are concerned, the hydraulic propeller has certainly proved itself to be quite equal, and I may say superior, to the twin screw; and I have good grounds for asserting, that as the power of engines is increased, this new propeller will tell to even greater advantage, and that it is one of the greatest maritime improvements of the day.

I wish to call special attention to the fact, that the naval architect must have greater command of speed with the hydraulic propeller than with the screw, because the screw is always limited as to diameter, and as you increase the power of an engine, and thereby the number of revolutions, the resistance is increased on the bows of the vessel, until the loss by slip gradually increases, and so you arrive at last at a point when the screw is making all slip, and no increase of power will increase the speed, nor can you multiply the number of screws.

But the turbine has no slip, and you may have several turbines in one vessel, and to whatever extent you increase the boiler power, so you increase the speed (under the law that the power is as the cube of the speed).

In light draught vessels the hydraulic will be an essential element of speed, (as Mr. Dudgeon wrote to the Brazilian Government).

I quote extracts from his letters.

The battle between the turret principle and the broadside has been always fought on the merits of gunnery questions alone, but there has been another very important question at issue, and that is, as to the most advantageous distribution of weights, and now the hydraulic propeller presents the same consideration as compared with the screw, only to a much larger extent.

The turret principle and the hydraulic propeller, when combined, will solve all difficulties attending the creation of an armour-clad ocean fleet of the line. And I do earnestly hope, that before another large vessel is laid down, a total change may take place as to the sea-going qualities our ships are to possess in future, otherwise I fear that more millions of money have to be wasted, and some great calamity has to occur, before public pressure is brought into play to enforce a return to those elements of seaworthiness, which have always given to the navy of this country the mastery of the seas.

At the Institution of Civil Engineers a short time ago, a diagram of a new type of war ship for sea-going purposes, of the genus *Monitor*, was proposed by a high official authority, and a broad principle was advocated, totally opposite to which I have advanced, namely, that our navy was to depend upon steam power alone.

I can only say that I trust this obnoxious intention may be frustrated by the naval advisers of the Crown, and I am confident that it will.

And now for the frigate class.

Here I put sea-going No. 1 on the diagram, then steaming, then fighting, and so on: the conditions speak for themselves, and necessitate a longer and a larger vessel, and one not suited for the line-of-battle, but to cruise and act unsupported. In fact, as the eye of the fleet.

And now for the corvette.

Here is our commercial protection against privateers and pirates. Therefore speed is first on the diagram, and sea-going quality second, and draught of water third, and fighting is fourth; so that it is evident we want no armour plating, but only armament enough to capture all privateers and speed to catch them, and by which to escape from all armour clads. Speed of 20 knots, if possible, and size enough to secure a safe ocean cruiser.

For the floating battery I recommend the *Monitor* type.

These vessels are suited for harbour defence, or they might be sent abroad for the attack of harbour defences, but they are quite unsuited for sea-going purposes.

For the gun boat I recommend the *end on* principle of fighting as of old, with a heavy gun behind, a stout shield, and no attempt at broadside armour protection; but the bow rendered unsinkable before the shield by partitions filled with cork to a level with the water-line.

I have made my remarks as general as possible; and I believe that on the

introduction of armour plating, had a committee of naval officers and naval architects been formed to consider the subject, and to lay down broad principles for the future of our fleet as an armour-clad fleet, we should have avoided what I consider to be a great calamity, which is to find, that, after so large an expenditure of money, we have produced a fleet which I believe to be inadequate in case of being required to perform the just expectations of this great maritime nation.

In one respect particularly I hope that I may be in error; but, judging from the reports of officers in whose opinion I have great confidence, I really do not believe, that with the exception of the two first which were built, the *Warrior* and *Black Prince*, and perhaps the *Achilles*, we have an iron-clad in our Navy, which could be safely trusted if placed in the middle of the Atlantic in the winter time, and to break a screw shaft, and if heavy gales and continued bad weather were to come on.

My remarks may bear the stamp of unsupported doubts and fears, but I am willing to bear the burden of this accusation, and shall be quite content to do so, provided what I have said may have the effect of producing a greater degree of consideration, in the future of armour-clad designing, to the matter of the safety of our ships at sea, and to the classification of ships.

And I would call attention to the fact that I do not believe there has been an instance on record of an iron-clad of our Navy having been caught in the open sea with her steam power disabled, and having in that condition encountered really heavy gales. They may not, I trust, actually founder, but I feel certain that an amount of hardship would be suffered and expense incurred which might have been, and ought to have been, avoided. And if ships are to be disabled by each gale, and are to be deprived of the use of their guns in bad weather, and if fleets cannot be navigated in compact order, as of old, I think I am borne out in saying that it is time a searching inquiry should be made into the cause of this. Because here lies the real issue of the whole question of the economy of our navy estimates. It does not lie in dockyard accounts, or in pigs of ballast, or in artificers' pensions,—but in the efficiency of our fleet!

DISCUSSION.

The CHAIRMAN: Whatever difference of opinion there may be as to the various subjects which have been treated of by Admiral Elliot, I am quite sure there can be but one opinion as to the importance of the matter which he has brought before our notice, and the very interesting manner in which it has been introduced. I am only sorry that we have so little time for its discussion. We will, however, if you please, now proceed to discuss it, as well as the Papers that have preceded it.

Admiral Sir Edward Belcher: The question of the hydraulic power has been alluded to by Admiral Elliot. I have great pleasure in verifying everything that he has recited, and I would even go a little farther, for I have heard the private opinion of Mr. Dudgeon, who, before the vessel was tried the first time, told me distinctly, "She never can succeed; I see nothing in her that can succeed." I shook hands with him that day, when the vessel had gone her 10 knots under great disadvantage, and with very bad coal—indeed, infamously bad coal, and with every difficulty against her. I was on board of her on the second occasion, and, although she was then much deeper, the vessel realized her 9 knots clear, and if the coal had been good on that occasion, and her funnel had been longer, I believe we should have had 10 knots then, immersed as she was. I have also been on board the *Nautilus*. I have had the pleasure of seeing her, and of witnessing her powers of steaming, and her powers of turning, which infinitely exceed those of any twin-screw which I have had the pleasure of trying in the river, and I think I have been in eight or ten trials of Mr. Dudgeon's twin-screw vessels in the Thames. One of the iron screws was coming down the river at full speed almost, with the certainty of coming stem on. The man commanding the iron steam—one of the penny boats—certainly must have known what we were about, but I could scarcely have put my finger between the two stems of those vessels, without risk of injury—she was turned suddenly round in half her own length. I am perfectly satisfied, that if all parties were heard, the turbine must turn the screw out entirely.

Mr. Dudgeon: As Sir Edward Belcher has just said, I was astonished. I think it right I should say I really was surprised at the result we got from the *Waterwitch* on the first day of trial. I may also say in regard to what Admiral Elliot has stated in his Paper, as to my opinion with respect to the difference between the value of the hydraulic power and my plan of the twin-screw, that I think he stated it most fairly; but there is one thing upon which I must differ a little from Admiral Elliot, and that is this:—my ship did happen the other day to strike upon a sand bank, which carried away her propeller, but it did not arise because she could not turn. I think the turning powers of the two systems would be found to be very nearly alike. The only other point I would call the attention of this Meeting to is this, that it is possible, if the Captain could have turned round by merely turning a handle on deck, instead of passing the order down to the engine-room, and could have been sure that the action was right, this, perhaps, would not have occurred. On that score, I believe that Admiral Elliot has only claimed what would be a great advantage of the system. With regard to the speed, there can be no doubt that the speed of the *Waterwitch*, as evinced, is something more than any one anticipated it would be, and certainly as much, or very nearly as much, as I got in the two steamers that were designed by myself for the Brazilian Government. But we still have a long way to go between 10 knots an hour, and 16 or 17 knots, which I have got with iron twin-screws, and I do trust that our friend Admiral Elliot will have an opportunity of putting the jet-system to the same test that we have put the twin-screw to. I believe, Sir, what you said was this, and I thoroughly agree with it, that Admiral Elliot, if he deserves nothing more, at least deserves great credit for the way in which he has put this subject before us.

Mr. E. J. Reed: I should like, Sir, before this subject drops, to say that I think Admiral Elliot will find very general concurrence amongst naval architects as to the validity of his first chief position, namely, that they are often subject to great disadvantages in not receiving sufficiently definite instructions as to what is desired in building iron ships, and any effort which may be made by Admiral Elliot, or any other gentleman, in that direction, in the way of relieving us of some of the immediate responsibility, which

does not really belong to us in many cases, and putting us into a different position—that of being the humble servants of the fighting, or military branch of the Navy—would be of great advantage to us. It is not for me to say that I concur in the doctrine that there has been any improper neglect of that question; it would be out of place for me to express an opinion upon that; but I do say, that in the future, if naval officers can agree upon what is wanted, and if we are told what it is, we shall stand a much better chance of getting credit, and avoiding discredit, than when we have to project things that are subject to all sorts of changes. I should like to say a word or two as to the hydraulic. I should be sorry to think that anything I say should be construed into anything like opposition to the adoption of that system, because I think it is very undesirable that a system which has started so exceedingly well as that has started, should encounter any prejudice; yet I wish to say in reference to it, that there are two points to be considered. In the first place, the vessels with which the *Waterwitch* competed are wretched specimens as regards propulsion. The *Vixen* and the *Viper* amount to very little more than very shallow floating boxes, heavily burdened on the sides with armour plating, but with a very light draught of water, and with very full bows and sterns. They each have a double stern instead of a single stern. Secondly, the *Waterwitch*, as compared with these vessels, has this advantage, which should not be lost sight of, that whereas these vessels trim by the stern, the *Waterwitch* is put down to an even keel, which had the effect of enabling us to fine the lines, and that must have had some bearing upon the result. But I only wish to make it clear that it can hardly be admitted that the *Waterwitch* principle is sufficiently established by competition with such a vessel as the *Vixen* or the *Viper*, which certainly are very inferior vessels as regards steaming power. At the same time, within limits, without admitting that one expected anything definite upon that question, most of us are prepared to admit that the *Waterwitch* did better than we looked for, and no one can fail to appreciate many of the suggestions which Admiral Elliot has made as to the advantages of that system as compared with screws; and I hope, that both amongst ourselves, and in the private trade, the value of that principle will be carefully appreciated. I must say that in the abstract, looking at the thing from quite an external point of view, it seems to me very difficult indeed to fail to concur with Admiral Elliot in his general classification of ships. It does appear to me, that if we had started with a principle such as we have laid down here, we should have been in a better position than we are. We should have had less variety in our ships, and it is not at all improbable that if the question had been put with thorough fairness and completeness before naval architects, as Admiral Elliot desires, we should have had what he mentions, namely, fewer vessels—every one of which was perfectly capable of maintaining her position upon the ocean. I know no reason why we should not. It does appear to me also, that it would be a very good thing, when we are building vessels that are to fight together, that we should sacrifice some of that enormous speed that has been obtained to a large extent in our faster iron-plated ships, because we have to make such enormous sacrifices to secure it. We should give the preference to sea-going qualities, to the turning, and to the fighting. If we were allowed to put these above the steaming qualities in a line-of-battle ship, it would be an immense advantage—if that were considered practicable, and if it could be carried out. It would be also a great advantage to find in the frigate class that the steaming power was preferred to some of those qualities which come later. I must say myself, the only difficulty I see in Admiral Elliot's programme is that the sea-going quality of a ship is greatly improved by the elevation of the ship above the sea surface. One of the difficulties of applying the turret system, and combining that with first-class sea-going qualities, is that it rather imposes on you the necessity of cutting down to a certain extent. But my main object in rising was to say that the Paper

which Admiral Elliot has read is an exceedingly valuable one, and demands the greatest consideration in the discussion of it; and I was the more anxious to say that, because I do feel at this moment that the turret system, whatever its merits or demerits may be, has suffered enormously in this country from the fact that there has been an unwillingness to bring the pretensions of the system within the scope of scientific investigation. I took it upon myself here four or five years ago to make certain statements about that system, and to what extent it could be carried, and the statements I made were not answered on that occasion, and never have been answered since; and up to this moment there is a disagreement between the persons interested in that question and ourselves, on points of science which admit really of no disagreement if a full investigation is made. I must say, in justice to myself, and considering the present position of the turret question, that nearly three years have now elapsed—certainly more than two—since I myself advised that a ship of the proportions of the *Bellerophon* should be built on the turret principle. The only reason why that ship was not built until now, was that the advocates of that system contended that the system was compatible with much smaller dimensions than I proposed. I have, what is to me partly the satisfaction, and partly the dissatisfaction, of knowing that we now are building a ship which is larger than the *Bellerophon*, and which only carries the guns and armour which I suggested for its dimensions three years ago, and that ship meets with the full concurrence of Captain Coles. I cannot help agreeing with the President of the Institution in his opening remarks this morning. I believe it will be scarcely within the power of any ordinary perversity to say that that system has not received a fair trial when that vessel has been produced.

Mr. Scott Russell: I wish also to thank Admiral Elliot for the very admirable Paper which he has read to us, and also for the principle which he has laid down, that it is the business not of the naval architect, but of the naval officer, to give us the specifications of what he wants us to do, and before we are told to do it; I would also say that if his example were followed, and if at the commencement of a new fleet there had been efficient naval officers to state exactly what they wanted, and to give order as he has done to certain qualities in the ship, and to say in addition to that what value they attached to each specific quality—that is to say, how much of one quality they would sacrifice for another—we should have a fleet as well classed as his figures on that Paper now are. I had some experience of that difficulty, for it was my duty, as you are aware, as one of the naval architects who were first consulted as to the creation of the new *Warrior* class;—it came to be my duty to go thoroughly into that question, and a very difficult question it was. Now I have to thank Admiral Elliot very much personally, and I think I may say on behalf of the profession, for having given us one of the earliest classifications by a sailor of the relative qualities in particular classes of vessels, and I think that table of his a most valuable contribution to our practical knowledge. Accepting his table then, I would differ from him in his mode of carrying it out, because it comes a little into my sphere of business. He tells me that he wants his liner to be a vessel in which sea-going qualities shall occupy the first rank. Now, I will at once tell him how he will get those qualities. I do not think he will get what he wants in a liner by the turrets. I think that his corvette and his frigate he may get out of the turret; but I do not think that he will get his liner out of the turret. I will tell how I think—I being as certain as a professional man can be upon a professional point—he will get it. If he will give his liner two tiers of guns instead of one, he will get every quality he asks for, and with satisfaction. The French have done so imperfectly, and, as I think, not satisfactorily, because the French had to do so by the conversion of wooden ships. But a ship having only a central battery, no end battery at all, with two tiers of guns, may have an infinitely more powerful armament than

any ship now afloat, provided she were built of iron, and provided her ends were quarters for the men and not guns. You would then have an enormous central battery; you would have no weights at the ends, overloading the water-lines. You would have a vessel lively in the sea; you would have a vessel with an extremely easy motion, because, for the second tier of guns, you would have to add an extremely small proportional weight of armament per gun. You have only to add seven feet of armour in order to get a double number of guns. Very well; now, the vessels that are built on that plan, the wooden vessels in the French Navy, are the vessels that are infinitely better sea boats than those are that are built of one tier of guns. The double-decked vessels are infinitely better armed. Therefore I say to Admiral Elliot, that, if he is really serious, and really represents his profession, when he says to us that he will sacrifice draught; that he will sacrifice stowage; that he will sacrifice steaming, provided that we will give him a sea-going, fighting, turning, and sailing vessel;—I say we will do all that, if he will take a double-deck central battery, and be content with a moderate length of ship; be content with a moderate speed, as he says he will be, and we will give him a handy turning, easy sea-going ship. But he must be content with that when he gets it, and he must not ask, after he has got it, that he should have all the other qualities that he did not specify. So much for the liner. As to the frigate, that is not a difficulty. If you say you want a frigate, we all know how we can give it you, and as fast as you choose to pay for it. One word as to the hydraulic propeller. I am not known, I think, at all, as an advocate of the hydraulic propeller. I have known of it for two generations, because it was first mentioned by the father of the present Mr. Ruthven, who was one of my masters in mechanics when I was comparatively a boy. I have known him and his inventions all my life; and I am very glad that his son has thought that it was a duty incumbent upon him to follow out his father's very early and very ingenious experiments. Now, as far as I know, the relative value of the propellers stands thus:—all the propellers, paddle-wheel, double-screw and hydraulic propeller, are equally good. Out of them all you will get the same speed,—but under very different circumstances, with very different combinations, and with very different elements of construction. Therefore I say to Admiral Elliot:—Go on; feel your way, puzzle your brains, get as many clever men to work as you can, go on with your hydraulic propeller, and I promise you that in the end you will certainly succeed; I do not say that you will ever get more speed than you will out of the others; I will not say that it will not take you a long time to get as high a speed as the others; I will not say that you will not have a great deal of trouble, and that it will not cost you an enormous quantity of ingenuity before you get your large orifice for vessels of large size, and before you get all the qualities you want in combination; but I promise you that if you go on you will get it. Therefore I must say that Admiral Elliot deserves very great gratitude for having brought forward this subject, for having published it, and I hope and trust he will go on till he brings out a very high degree of success, because the hydraulic propeller has peculiar advantages, as it seems to me, in its application to vessels of war. As I am on my legs, I will say one word on the two other Papers which have been read. I regret that Mr. Bourne has left the room, otherwise I should have made a few remarks on his Paper, in which I confess, he has most wisely shown what the various elements of the resistance are, and how they contest with each other; because it is quite certain that the shape of ship which will give you least resistance, as far as displacement is concerned, may, by its great length and fine lines, give you a slow vessel on account of the large quantity of surface which it exposes to the skin resistance or drag of the water, and it is always a question of compromise, I call it, in designing a ship, whether you will extend her, and make her very fine to get little resistance or displacement, or cut her off in order to get little length. With

regard, also, to the Paper read by Mr. Reed, I venture to make this one statement. If there be a more important thing than another to be thought of in the construction of iron ships, it is this:—not to have strong places, and not to have weak places; not to have strong places, because by "strong" I mean rigid, exceptional places. Let no part of your ship be exceptionally strong, or exceptionally rigid, because where it is too strong—though you may think that an absurdity—where it is too strong, there it is the surest to be broken. It is the rigid parts of an iron ship that are cut through, and that destroy the ship. It is the flexible or weak parts that yield and do not destroy the ship. But when you go to too great flexibility, you go the other way, and you get then the metal of the ship yielding, and these thin places become serious sources of danger. But I think it is important that you should remember that they are not more serious sources of danger than the thick places, and if I were to put the whole theory of iron shipbuilding into a sentence—I should put it into this sentence—I should ask for perfect continuity, as near as you can get it, everywhere; that is to say, I should ask for a homogeneous skin; I should put as much metal as possible into the skin; make it as uniform as possible, and have no hard places and no soft places. If you will do that, and depend upon these two things, uniform and pervading thickness of skin, uniform strength and uniform flexibility, and not make hard and strong places, nor have alternating weak places, you will have done all that you can to make a good, permanent, safe iron ship.

Admiral Elliot: I wish to make but very few remarks in reply. In what Mr. Reed said I think he may have conveyed an impression which I do not think he intended. He spoke of the advantage which the *Waterwitch* had on account of her keel. When I say that she is one of the same exact class of vessel as the *Vixen* and the *Viper*, the same weight, the same displacement, the same length, the same midship section, the same power, and goes at the same speed, there is no great room I think for any great improvement in the *Waterwitch*. There may be a slight advantage at the bow, certainly; I should hardly say there is any, but there may be a little, and that is a question, I think, which is quite capable of being decided. It depends entirely upon whether we admit that a vessel shaped alike at both ends is a faster vessel than a vessel that has an overhanging stern, and with her buoyancy higher up, hanging over the water as it were. Now I maintain that a vessel shaped alike at both ends will be the fastest, and it is one of the principles of the hydraulic propeller that the vessel will be alike at both ends. I believe that in that way you will get as good and as fast a vessel as in the other way, but that is the only difference between the *Vixen* and *Viper* and the *Waterwitch*. With regard to the turret principle, I did not quite understand as to putting turrets into the vessel. I mentioned it on account of the distribution of weights. The turrets would be in the centre of the ship and would dispense with the necessity of the bow and stern batteries. I think this is a most important consideration with regard to the distribution of weight, which, as I said in my Paper, has been lost sight of. I have one other remark with regard to the turret principle. Mr. Scott Russell has spoken of two decks, but I do not see what object he has in view; I put the turrets in the middle and get them as high or low as I like. I can raise my deck as high as I like, and, as I believe it would generally be adopted, could have a deck above for the men to work in just over the turrets.

Mr. Scott Russell: You get few guns; I get many.

Admiral Elliot: I am coming to that. With regard to the number of guns—that is the most precious point upon which the turret will exceed the broadside principle. A gun will be of no use at all unless it be a very heavy one indeed—the very heaviest that can be put into a ship; and I say I do not

believe that these guns can be worked in a broadside. I saw the other day the guns in the *Bellerophon*, and I believe that from the way in which they are exposed, with the gun-carriage, in the first place, subject to be destroyed or injured by grape shot, they would be useless; besides, I do not think they will ever control those guns. I have heard of one of our war ships, in which the men were ordered to fire their guns. They went to their guns on their own main deck; the vessel began to roll; the water came up the side of her, some 12 feet above the port; it filled the gun deck with water; the men were washed away; the guns were perfectly out of control, and I believe the Admiral, who was on board, had to swim for the hatchway.

Mr. Scott Russell: What vessel was that?

Admiral Elliot: The *Lord Clyde*. I believe I am stating the truth. I was told it by an officer who is not in the habit of exaggerating. He told me that the Admiral had to swim for the hatchway. That was the result. The Captain ran on deck, lowered her ports, and put her head to sea to get the water off the deck. This, remember, was not in a gale of wind. I do not believe, then, that these ships, if they use their sails, will be able to fight their guns. But in the turret principle you can turn the gun fore and aft, and load, and never shew out of the port, except at the moment when you are firing; whereas on the broadside principle you must be exposed, and if a shell should come in, I can well imagine what the case would be. You may depend upon it that the turrets will be the best, because they are the natural means of carrying the heaviest guns. Ramming, too, will be a work that will have to be done. It was done at Lissa. A vessel that can ram at both ends without turning round—first one way, and then another way, without turning round—will have a very good chance on the hydraulic principle. I would say with regard to Mr. Dudgeon's vessel, the *Mary*, that she could have turned round if the orders had been rightly given, but with the hydraulic she would not need to have turned at all; she would have stopped dead, and gone stern foremost at any speed you liked. I do not know that I have any other remark to make. In fact, I am quite contented with the reception with which my Paper has met. I believed it would have been met with a great deal more of disfavour. As to the speed—we were told by some of the great engineers of this country—I believe it is on the records of the Civil Engineers' Institution—that we should not get half the speed, or that we should have twenty-five per cent. less speed. Now, we have proved that some of these predictions have not been true, and I firmly believe that as you increase the power you will increase the velocity as compared with the screw.

Mr. Galloway: The subject matter of this Paper is very interesting, and as there are other Papers to follow I shall not now speak upon it. There is, however, in that valuable Paper which was read, a very grave charge in respect to the present state of the Navy. Now, if that charge be really true it is very humiliating, and I should like to ask the Chief Constructor of the Navy, who is present, two questions. (Cries of "Question" and "Order.") Might I be allowed?

The Chairman: It is irregular, after the reply has been made, to renew a discussion.

SOME INVENTIONS FOR MARINE PROPULSION RE-INVENTED.*

By J. Mac Gregor, Esq., M.A., Associate Member of Council.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

The object of this Paper is briefly to call attention to some of the numerous cases in which inventions relating to marine propulsion have been patented over and over again, evidently in ignorance that they had been already invented by other people.

This needless repetition of effort in ingenuity and labour, and this expense of time and money are, unhappily, too frequent in other branches of mechanical invention, but it is specially deplorable in the case of machinery for propelling ships; because full information may be had free, or at a very small expense, as to what has already been invented in this direction, and because a large field of untried ground remains to be explored by those who are eager to improve marine propulsion.

The following remarks are made after a careful examination, for official purposes, of the patents on this subject, since the earliest granted to Ramsay, 250 years ago. But although more than 1,000 patents were thus investigated, it may be better, for various reasons, to refer chiefly to the 800 patents granted before 1857.

First, with regard to inventions as to the source of power applied for propulsion, we find that besides those relating to steam, there are ten inventions for obtaining the power from animals, thirteen from wind (exclusive of sails), six from springs, three from gunpowder, twelve from compressed air, thirteen from gas, and six from electricity.

The patentees of at least one half of these described their inventions as if none other had been thought of in the same line before, and many of them evidently took out their patents after long years of labour and anxious experiments, which half an hour's reading of books now available at the Patent Office would have saved. This is made even more

* Received 16th March, 1867.

evident by the large number of patentees who proceed only so far as Provisional Protection. Out of one hundred patents in 1862–4, one half did not go further than the Provisional Specification.

Other lines of thought and trial in this department seem to have been followed with perseverance, even though all former efforts were known to be unsuccessful. Such cases indicate perhaps, that sooner or later, something really practicable is to be obtained when so many minds pertinaciously insist on following the same general idea, being evidently under the sure impression that some one at last will meet the "coming plan."

Thus, there were fifty-nine inventions for applying power to propel by discharging water from a vessel, and it is only lately that this mode has been found really useful for a particular case. Again, for applying power by the discharge of gas, fire, or steam, there were twenty-nine patents, but it is only within the last few years that we have seen the little "shilling steamboat," of which so many thousands have been sold in the toy shops, moved in this manner.*

There are other well-known propellers, which it is positively tedious to trace as they recur century after century, each time invented again as if a complete novelty, and each time turning out a complete failure; such, for instance, as the vertical floats on endless chains, of which there are more than twenty patents almost identical.

If we direct attention to the paddle wheel itself we find that (omitting steam as the prime mover) there are seven patents for turning paddles by wind, nine by animals, thirteen by men, and fifteen for shaping the paddles like a drum. One patent later than all these is indeed original enough, for it proposes to work the paddle-wheel by steam and manual power combined.

As for the separate parts of the paddle wheel, "feathering floats" are patented scores of times. Many of the inventions relating to these are new and useful, or, at least, suggestive; but still we have repeated cases of precisely the same plan of feathering paddles patented repeatedly, and affording clear evidence at once of the ignorance and the ingenuity of the successive inventors.

The screw-propeller has a like series of duplicates of invention; where there are five patents for an increasing pitch, fourteen for an adjustable pitch, sixteen for screws to steer with, thirteen for screws in tubes, six for screws worked by manual power, six for screw and paddle combined, and twelve for that form which was indeed the first of steam screw-propellers (suggested more than a hundred years ago), and now called

* At the Paris Exhibition there will be seen in operation in July a steam canoe, on this principle, exhibited by the Canoe Club, of which the Prince of Wales is Commodore.

"twin-screws." As for propellers with fore-and-aft motion, there are nearly one hundred and forty patents before the year 1858, and precisely the same plans have been frequently patented since, and within the last ten years.

The prodigal waste of energy, in patenting again what has been done before, is wearisome to the ingenious but ill-informed mechanic, and a sad loss to the community; because the inventor uses time and labour upon a futile search in a heap of refuse, instead of starting forward on the unemployed ground where rich ore still lies undug. Ignorance of former inventions was no doubt excusable in past times, when the efforts and results of others' works were imperfectly recorded, and access to the records was difficult; but it is by no means satisfactory to perceive that this ignorance of old inventions and of recent inquiries is quite as frequent now-a-days as in former times, though all the information that can be required may be obtained by very little trouble indeed in each special branch of industry where an inventor's mind may be led to search.

Perhaps some clue to this phenomenon of ignorance and ingenuity combined, is found in considering the following relative numbers of different classes of the community among the inventors in the eight hundred patents referred to. Of these, I find that there were engineers, two hundred and seventy-two, and private gentlemen, two hundred and fifty-two; while, of the class we might expect to be most alert in inventing marine propellers, there were very few—only fourteen Naval Commanders, eleven shipbuilders, eight shipowners, and five mariners.

We may still, indeed, be consoled by the hope that the small proportion of the nautical class here represented were perhaps the inventors of the most useful inventions; but after all, there remains the undoubted fact that much mechanical genius is now being wasted—that the knowledge which would make it profitable is readily to be had—and it appears to me that much might be effected to remedy this evil, if every Member of this Institution would do his best to circulate information among his inventive friends, and when he observes any man in his employ or of his acquaintance, whose turn of mind is for mechanical invention, let him direct such a person to the records of what is known in this particular line, and thus help to place his foot on the highest rung of the ladder hitherto attained, in hopes that he may then make upward progress.

DISCUSSION.

Mr. GALLOWAY: I would just remark, Sir, that a number of years, I cannot tell you how many, but certainly a great number, must necessarily elapse, really and truly, before plans and inventions can become properly known. That is a defect which some say is to be remedied. I hope the day will come when it will be remedied. My desire is, let proper conditions exist; let a proper tribunal be in operation to test inventions; then the age we live in will receive the advantages of that which is truly good; and that which is worthless, when once known, will be made so public, that men will have nothing more to do with it. I sit down after these few remarks.

Mr. COWPER: I wish to say a word or two in reference to the Patent Office; although a very useful office for the publication of specifications of patented inventions, it is still without full and proper indices of patented inventions, and is altogether without indices of inventions and processes not patented, so that it is impossible to find out there (or indeed anywhere else) whether an invention is old or new, and the labour of searching for inventions is very great. I went in two or three cases to investigate the novelty of a patent professionally for other parties, and I found the labour excessive. In one case it cost me a hundred and fifty guineas to search for one thing alone.

The CHAIRMAN: I think we are very much indebted to Mr. Mac Gregor for pointing out how many steps of the ladder we must climb, before we get up to the level which he has indicated. As far as the question of the hydraulic is concerned, I may say, that as far back as the year 1818 I tried my hand at two or three of these inventions. Latterly, I was connected with what was mentioned in the Paper, a vertical set of paddles.

Mr. MAC GREGOR: Vertical floats—or external?

The CHAIRMAN: Mine were internal, in a groove between two keels, terminating astern between two rudders. That was in 1818. As to the records at the Patent Office, I have had occasion to investigate some of them, and I found that after about one week's hard work I got through four patents. Then I was told that, "if I hired a person who was conversant with these affairs, in the course of about one and twenty days more, I might get a sight of what I was in search of." I think we are very much indebted to Mr. Mac Gregor for the information he has given us.

SOME REMARKS ON APPARENT NEGATIVE SLIP.*

By W. J. Macquorn Rankine, C.E., LL.D., F.R.S., Associate Member of Council.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

1.—When the attempt has been made to account for the apparent negative slip of a screw propeller by the fact of its laying hold of a current of water that is following the ship, this objection has been raised:—that the forward momentum impressed on that current in a second is equivalent to the resistance of the ship; that the backward momentum impressed by the screw on the propeller-race in a second is equivalent to the thrust of the screw, which is equal and opposite to the resistance of the ship; and that, consequently, even if the screw were to take hold of every particle of the following current, that fact would account for a diminution of positive slip only, but not for negative slip. That objection is fully stated in the Paper read last year by Mr. Reed, Chief Constructor of the Royal Navy.

2.—If the velocity of the following current in which the screw worked were simply the mean forward velocity of the ship's wake, the objection in question would be unanswerable; for it is the momentum per second due to that mean velocity which is equivalent to the resistance of the ship, and to which the reasoning just mentioned applies.

3.—But the water affected by the passage of the ship through it has various reciprocating or wave-like motions combined with the mean velocity of the wake; and, in particular, there is forward motion under every crest, and backward motion under every hollow, of the waves that accompany the ship. The velocity of those reciprocating motions is not connected directly with the resistance of the vessel—in fact, their resultant momentum is equal to nothing; and it is only the momentum of the uniform current which remains after the wave-motions have died out, that is equivalent to the ship's resistance.

* Received 28th March, 1867.

4.—Hence, if there happen to be, as there generally is, the crest of a following or filling wave under the ship's counter, the water of which the screw lays hold has a temporary forward velocity over and above the permanent velocity of the wake; that temporary forward velocity, indeed, may be many times greater than the permanent velocity of that current whose momentum is equivalent to the resistance of the ship; and thus any extent of apparent negative slip may be accounted for.

5.—The existence of a following wave explains also the fact that any considerable apparent negative slip is always accompanied by waste of motive power, the resistance to the motion of the engine increasing in a greater proportion than its speed is diminished. For amongst the laws of wave-motion are the following:—that all forward motion of the particles in a wave is accompanied by an elevation of level, and that the pressure against a body in front of the wave, due to that elevation of level, is exactly equal to the pressure required to impress the forward motion upon the particles of water. Such is the pressure exerted upon the stern of a ship by the wave which follows under her counter, when that wave is undisturbed by the action of the screw. But the screw, by checking or reversing the motion of the particles of water, lowers the level of the crest of the following wave, and diminishes the forward pressure which that wave exerts on the vessel. That diminution of pressure is virtually equivalent to an increase of the ship's resistance; so that the thrust of the screw must be equal, not merely to the resistance properly due to the dimensions and figure of the ship, but to that resistance increased by a force equal to the diminution which the action of the screw produces in the pressure exerted on the ship by the following wave. Thus the total thrust of the screw is increased above its effective thrust—that is, above the proper resistance of the ship, in a proportion greater than that in which the speed of the screw is diminished through apparent negative slip, so that the result is an increased expenditure of motive power above what would be required if the screw acted in water not affected by wave-motion.*

6.—The principles of the preceding paragraph do not apply to uniform forward motion of the particles of water produced by friction; because such motion is not accompanied by the production of a swell; and hence (as Mr. Froude has pointed out) the permanent following current in the ship's wake due to frictional resistance does not give rise to a loss of thrust, as the wave-motion of the particles of water does.

* *See* a Paper "On the Mechanical Principles of the Action of Propellers," *Transactions of the Institution of Naval Architects*, 1865, Vol. VI.

APPARENT NEGATIVE SLIP IN SCREW-PROPELLERS.*

By W. Froude, Esq., Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

There are two separate circumstances by which what is called negative slip may be occasioned. (1.) The operation on the propeller of the dynamic conditions belonging to the "wake." (2.) The operation on it of the dynamic conditions belonging to the "dead water."

These two circumstances are, indeed, in appearance, closely allied, since, *primâ facie*, the distinction between wake and dead water does not attract attention. But a very real and important distinction exists between them, and when due account is taken of this, it will be seen that the negative slip, which is attributable to the former, expresses a saving of power; that which is attributable to the latter a considerable loss of power.

In my remarks on Professor Rankine's Paper of 1865, which were embodied as a distinct Paper in the *Transactions*, I discussed the nature of the circumstances now referred to; and I pointed out, in particular, that there resides in the wake a dynamic virtue, or worth, adequate to the development of an apparent negative slip, having a velocity equal to half the forward velocity of the wake, provided the propeller were one of a theoretically perfect character, and I shewed that in this case a distinct saving of power must be the result. I explained also the nature of the dead water, and described the loss of power which must result to a screw propeller of ordinary character and position under its operation. I did not, however, point out, for I had not then as distinctly appreciated as I have done since, how negative slip might be developed under the operation.

I venture now to treat of both circumstances at somewhat greater length, and with more direct application to the subject of this Paper.

I advert, first, to the action of the wake.

* Received 11th April, 1867.

By the " wake" I mean that current which is seen to follow a ship or other body moving through a fluid, and which consists of an assemblage of particles on which the ship or body has impressed motion *in transitu*, leaving them behind, with the motion impressed on them.

For a body moving with a constant velocity in a fluid indefinitely extended in all directions, the wake is precisely the " dynamic equivalent" of the continued propulsive force employed in overcoming the continued resistance experienced by the body. Nor does the proposition need to be qualified if applied to a ship moving at the surface of the water, if her form be good and if her speed be kept within proper economical limits. I will explain this more fully, for the relation between the wake and the propulsive force will be found to turn on it.

By dynamic equivalent I mean this. When a force having a given magnitude and direction is employed in giving motion to matter, the momentum generated in a given unit of time, that is to say, the product of the weight set in motion, multiplied by the velocity imparted to it in the given time (counting solely, but wholly, the velocity generated in the direction of the force) is a given constant quantity, the same in amount, whatever be the magnitude or character of the mass or masses on which the force acts, and in whatever manner the force be distributed amongst the particles.

Thus, when a force of one ton acts for a second in a given direction on a mass the weight of which is one ton, the mass, as is well known, receives the velocity of 32 feet per second in that direction. And the momentum generated may be expressed by 32×1, that is, 32 unit tons-feet of momentum, or by $32 \times 2{,}240$, that is, 71,680 unit pounds-feet of momentum, according as we take tons or pounds as the unit of weight. And if the time of action, or if the force, be increased in a given ratio, the resulting momentum will be increased in the same ratio; but so long as the time and the force remain unaltered, the momentum remains the same, though the weight acted on be varied in any assignable ratio, since the impressed velocity will at the same time be varied, in a ratio precisely the inverse of that in which the weight is varied.

Or, again, if the mass acted on consist of an aggregate or integral of infinitesimal masses, acted on either separately or in combination, simultaneously or in succession, provided the aggregate of the force employed in the given direction, and the time of action remain unchanged, the momentum will then be simply the integral of the momenta developed in the individual particles, and must be the same in total amount, whether infinitesimal units of matter, or infinitesimal units of time, or both, be taken as the basis of the integration.

This integral product, being invariable for any given force acting in a given

direction, through an unit of time, and directly proportional to the force, I call the *dynamic equivalent* of that force; and its equivalence to the force is in no degree impaired by the circumstance that any amount of transverse velocity may have been simultaneously impressed on the same or on other contiguous masses by what appears to be the operation of the same force. Such velocities, when they exist, are irrelevant to the measure of the direct force, being due, not to the force itself, but to its transverse derivatives or components.

The proposition is, in fact, the direct result of the primary law of dynamics usually symbolised by the expression $d\,v = f\,d\,t$ when regarded in the abstract; or, as it may be put, if we wish to adapt it to quantitative interpretation, and to the operation of a force acting uniformly for a given unit of time, $v\ W = f\,g\,t$: and since, in round numbers, $g = 32$ and a cubic foot of salt water weighs 64 lbs., we may, with a view to marine questions, conveniently modify the expression into the shape $F = 2\ m\ v$, where (F) is the force in pounds, which acting for one second on (m) cubic feet of water, impresses on it the velocity (v) in feet per second.

Now, when a ship moves through the water she experiences a disturbance of that equilibrated fluid pressure to which she was subject while at rest; and the aggregate components of that disturbance, when summed up in the line of the motion (excluding wholly those which are transverse to it), are what we call her "resistance."

But this resistance is but another name for the aggregate of the forces parallel to her line of motion, which she (in whatever manner) impresses on the particles from which it is derived; and if we assume that the ship's velocity is maintained by an external force, that force—which we call the "propulsive force"—is on the one hand equal to the resistance, and on the other to the sum of the forces in the line of motion, which she impresses on the particles of fluid which she traverses. "Resistance" is the sternward force which the water impresses on the ship in the line of her motion. "Propulsive force" is the forward force which the ship impresses on the water in the line of her motion. In both terms, the derivative or transverse forces are disregarded.

This impressed force must give forward motion to the particles on which it is impressed; and the succession of particles which have become the recipients of the motion constitute, in fact, the "wake:" and it is the direct consequence of the foregoing exposition of what is meant by dynamic equivalent, that the integral forward momentum of the segment or frustum of wake generated in each unit of time (say each second), is the dynamic equivalent at once of the resistance and of the propulsive force; and this relation between the wake and the resistance exists alike, whether that resistance arise in the shape of unbalanced pressure on the bow, or unbalanced pressure on the stern, or

of skin resistance—whether, in fact, the water be *pushed* forward, or *pulled* forward, or *rubbed* forward.

The dynamic equilibrium between the action of a force on matter free to move, and the reaction of that matter, must here, as elsewhere, subsist in virtue of the adequacy of the momentum in the direction of the force, imparted to the matter by the force. Thus, for example, all ships which employ, say a ton of propulsive force, generate one and the same momentum of wake per second; and this momentum is the same as is impressed on a ton of matter falling freely by gravity for the same unit or second of time: we may, in fact, apply to the relation between the wake and the propulsive force which drives the ship, the expression just now put forward, $F = 2m\,v$.

It should be observed that this condition remains inherently imbedded in the wake, so long as the wake is subject only to the reaction of those particles or volumes of contiguous fluid with which it becomes intermixed. Under such circumstances momentum is indestructible. The velocity of any given segment of wake is reduced only in the exact ratio in which its volume becomes enlarged.

This relation between a ship's wake and her resistance is but the direct result of the fundamental law of dynamics just now adduced, applied in its most direct and simple form to a hydrodynamical question,* and the relation may, I think, be correctly termed "the fundamental condition of resistance;" because, if a ship could continue to move without generating a wake, it is clear she would move without resistance; but, whereas in moving she experiences resistance and generates a wake, the wake being the correlative of the resistance, the two circumstances are indissolubly connected, and are mutually determinable in virtue of that relation.

If we carry on the same line of thought, it is obvious that the "fundamental "condition of propulsion" must, in its relation to the fluid operated on, be analogous to, and indeed precisely the correlative of, the "fundamental condition of resistance." Just as each ton of resistance experienced by the ship implies that a forward momentum, the dynamic equivalent of a ton of force, is being continually created in the wake, so each ton of propulsive force, employed in overcoming that resistance, implies that a sternward momentum, alike the dynamic equivalent of a ton of force, is being continually impressed on the volumes on which the propeller operates, which therefore are formed into a sternward current.

* The truth and practical value of this application of the law would, I think, have long since been apprehended and utilised by practical men, but that, from the fact of their usually dealing with hydrodynamical questions by the intervention of specialised formulæ, such questions have come to be regarded as if they were *sui generis*, and depended on a separate set of dynamical principles, whereas those formulæ when truly understood and applied are but specialised applications of ordinary dynamical laws.

Now, equal and opposite momenta, if brought into collision, impact, or combination, will mutually destroy each other: hence, if the current constantly created by the propeller impinge on, or become intermingled with the current of the wake, the sternward momentum of the one will precisely neutralise the forward momentum of the other; or, what is in effect the same thing, if the propeller operate directly on the wake, it will precisely neutralise the forward motion which the particles of the wake possess.

That this result is actually realised in the operation of the screw-propeller, any one may satisfy himself by careful examination of the wake of a screw ship, especially if he compare it with that of a paddle ship or a sailing vessel.

Behind the sailing vessel, for a considerable distance, he will see a well marked forward current, having, indeed, a diminished velocity, but at the same time a widened volume, as the vessel recedes from the point of observation.

Behind the paddle-wheel ship the two sternward currents thrown by the paddles, and the forward current of the wake between them, may be seen long to maintain their independent vitality.

Behind the screw ship, when working under ordinary conditions, at but a short distance astern, where the conflicting motions of the particles have had time for mutual adjustment, it may be seen distinctly that the particles retain neither progressive nor retrogressive motion, though the circumferential motion impressed on them by the oblique action of the screw blades distinctly survives.

The exactness of the observation becomes markedly verified, if it be extended to cases in which either the ship's resistance is enhanced by some adventitious circumstance, such as a head wind, or a vessel in tow, or her propulsive force is aided by the effort of her sails.

In the former case, since the ship's resistance forms but a portion of the whole resistance, it absorbs only a portion of the whole propulsive force: thus the momentum of the forward current of the wake, being generated by, and the equivalent of the ship's resistance separately, is less than the momentum of the sternward current, which is generated by and is the equivalent of the whole propulsive force; and is therefore overpowered by it.

In the latter case, since the ship's resistance represents the combined propulsive forces of the sails and of the propeller, the momentum of the forward current of the wake, being the equivalent of the whole combined force, exceeds, and therefore overpowers, the momentum of the sternward current thrown by the propeller, since this is the equivalent of only that share of the force which the propeller supplies.

A screw ship, when steaming against a head wind, or when towing another ship, throws a visible sternward current; when aided by her sails, she drags after her a visible wake.

It may then be stated broadly, as a fundamental proposition, that the sternward virtual velocity of any propeller which operates directly on the wake must, in order to propel the ship, be such as precisely to neutralise the forward velocity of the wake: and, conversely, that the adequate propulsive force will be maintained by any propeller which so operates on the wake as to neutralise its forward velocity.

Primâ facie, therefore, it would seem that a propeller whose effective velocity as regards the ship is exactly that of the ship herself, and which would, therefore, simply bar the forward motion of the wake, would adequately fulfil the fundamental condition of propulsion. With such a velocity of propeller, the apparent slip would be precisely zero; and it would seem to follow that though propulsion *without slip* is theoretically possible, negative slip as a fruit of the wake is an impossibility.

But if we disregard for a moment the mechanical difficulties which practically limit the arrangement of propulsion, and adopt as our standard an ideal propeller which would accomplish its work in the most perfect manner imaginable, we shall find that, theoretically, propulsion may be maintained by a propeller having a mean negative slip equal to half the mean forward velocity of the wake at the point of operation.

For we may conceive a propeller, whose blades, absolutely at right angles to the line of the ship's motion, enter the current of the wake with a forward velocity precisely equal to that of the current at the point of entry, and are of such number and disposition as to pervade every point of it homogeneously; and we may assume that each blade in succession, when it has thus assumed its due position, shall then, and not till then, begin to press sternward with a steady force, maintaining the pressure until the group of particles of wake on which it operates shall precisely have been robbed of its forward velocity.

Each of these blades, thus beginning its operation with a forward velocity equal to that of the wake, and by degrees coming absolutely to rest, would thus, on the one hand, have adequately fulfilled the condition of propulsion, by neutralising the wake, and, on the other, would have had a mean forward velocity, and, therefore, a mean negative slip equal to half the velocity of the wake.

All the conditions, however, which have been enumerated as essential to the attainment of this theoretically possible result, the homogeneous distribution of the propulsive force throughout the body of the wake, the gradually accelerative action of the blades, and the squareness of their pressure against the water, are very difficult of fulfilment in practice. Possibly the nearest approach to their fulfilment might be attained by a well-considered adaptation of a form of propeller, the use of which is not

uncommon in American rivers, and which might be found not unsuitable for our own. I mean the sternwheel, which might be fitted with feathering floats, having such geometrical arrangement of parts, that each in turn should act on the water with regular accelerating force, and with approximate squareness.

But with a screw-propeller, occupying its usual position in the deadwood, the prescribed conditions, instead of being fulfilled, are simply outraged in every particular; and though, as I have shown, negative slip of definite amount, as a fruit of the wake, is theoretically possible, I do not believe that it has ever thus been actually realised.

The second possible occasion of apparent negative slip to which I wish to draw attention, is the operation of the dead water on the propeller.

What is meant by dead water is the volume or volumes of water collected behind the stern-post of a ship when in motion, and behind her square tuck when she has one—water which accompanies the ship almost without change. When the stern-post is thick, and the tuck broad, as in our old timber line-of-battle ships, the volume of water thus carried is very large; indeed it was mentioned to me by one of the wardroom officers of such a ship, that when the screw was hoisted out of the water, and the ship going 7 knots under canvas, he had been lowered down into the well, and had bathed there without inconvenience.

The distinction between water thus circumstanced, which we term dead water, and the wake, is this; that whereas the wake consists of constantly renewed volumes, on which permanent velocity has been freshly impressed by the ship as she passes them, and which thus maintain the constant demand on her propulsive force, the dead water, having been once for all put in motion, and accompanying the ship almost without change, expresses no part in the constantly maintained resistance; the motion which has been imparted to it representing a force not now operating, but which did operate while the motion was being at first imparted.

The block or volume of dead water thus carried in the screw aperture of a timber line-of-battle ship is probably near 200 cubic feet, or between 5 and 6 tons in weight.

Now when the screw is set to work in this aperture, the dead water is no longer allowed to remain undisturbed. Each blade of the screw as it sweeps past the stern-post disperses the whole of the dead water with a violent shock on the shaft; while, from the inherent necessities of the case, the dispersed dead water is instantaneously replaced by fresh volumes taken up from the surrounding water, to which therefore the ship's velocity has to be rapidly imparted. And the communication of velocity to the water of replacement, forms an adventitious addition to the ship's resistance, and causes a retardation precisely equal to the propulsive shock occasioned by the dispersal.

Thus, in the case of such a line-of-battle ship as was just referred to, if we assume her to be driven at 10 knots by a two-bladed screw, making sixty revolutions, the operation must be repeated twice per second, and, therefore, one hundred and twenty times per minute; the 200 cubic feet of water are dispersed with a sternward velocity of about 10 knots, representing thus an extra thrust on the screw shaft of 6,000 pounds or 7,000 pounds; while by the process of replacement, a retarding force of like amount becomes immediately impressed on the square tuck and stern-posts to which the dead water belongs.

But though in this struggle (if I may use such a word) between the propeller and the dead water, a precise balance is maintained between propulsive shock delivered, and adventitious resistance called into play by the compound operation, not only is a great deal of force exerted to no purpose by the propeller, but the mean speed of rotation of the propeller must undergo great reduction, and this in such a manner as to be capable of exhibiting in almost any degree the phenomena of negative slip.

This will be best understood if we, in thought, follow the action as it would exist if the propeller consisted of a single tolerably narrow blade.

So much of the circumferential travel of this blade as is occupied in its passage behind the stern-post through the dead water, is, as has been shown, purely neutral as regards propulsion; nor does the reaction experienced by the blade in its transit, bear any necessary relation to the proper resistance of the ship, with which, indeed, it has almost no connexion. The dead water to be operated on might be made very large indeed in a ship having very fine lines, and a very moderate scale of resistance.

During the remainder of the circumferential travel of the blade, while it is operating on the free water outside the ship, its normal propulsive force is freely and usefully developed.*

* There is, indeed, a partial exception to be made to this statement, arising out of the fact that the whole water about the run of the ship possesses, in a minor degree, the character of dead water, because while it is falling inwards on the path of the ship, it carries with it, for the time, an element of forward motion, which element of forward motion, though not resident in an unchanging volume accompanying the ship at her full velocity, is itself transferred as a forward motion from particle to particle; thus the element of motion accompanies the ship, though the particles in which it resides are changed, and no renewal of external force is demanded for its maintenance. This transference of forward motion partakes of the nature of wave-motion, and belongs to that series of phenomena which Professor Rankine has so ably investigated under the denomination of stream lines, and which are referred to in his Paper of 1865. To displace or disorganise this replacement by a stern-ward force, such as that of a propeller, introduces an adventitious resistance closely analogous to that introduced by the displacement of the dead water, and, *pro tanto,* produces similar effects on the propeller, but these are generally smaller in amount from the circumstance that the aggregate forward momentum resident in the stream-line replacement within reach of the propeller, is itself probably smaller than that resident in the dead water.

The region of its preponderating action is, however, that near the upper part of the run; and this inequality of distribution will be found, on the whole, to increase rather than lessen that action of the dead water proper, to which I am calling attention.

Still it is while the blades are in the position most clear of the body of the ship that their propulsive force operates effectively, and the propulsion of the ship will be performed during these parts of the revolution, with much or little slip, according as the area of the blade, the diameter of its path, and the fineness of its pitch are favourable or otherwise to the reduction of slip. The mere alienation of propulsive force, while the blade is traversing the dead water, does not interrupt the progress of the ship. The short interval, during which propulsion ceases, is analogous to that during which a rower is preparing for the succeeding stroke.

But during these intervals the propeller blade is employed in overcoming a circumferential resistance far more severe than at any other period of its rotation, and since the force which drives it is of given amount, the rotation must during these intervals be proportionately retarded.

The retarding force thus encountered by the propeller might, under assumable conditions, be such as almost wholly to arrest its rotation. But the ship meanwhile is progressing with almost unaltered velocity; a velocity due to the operation of the propeller during its transit through the free water. And to count the slip by comparing the mean speed of the propeller, (including its retarded speed through the dead water) with the simultaneous progress of the ship, is a method as fallacious in principle as it would be were we to count the slip of the oars in a rowing boat, by comparing the total range of oar stroke with the total progress made by the boat during the whole time between the commencement of a given stroke and the commencement of that which succeeds it.

Were we to take a flat-bottomed boat with a square stern, that is to say, with a square tuck occupying the whole section of the boat, and propel the boat by a single-bladed propeller, having the axis of the shaft level with the floor of the boat, one half of the revolution would be performed in dead water, with a very greatly retarded speed of rotation, but without useful effect; the other half would be performed in free water, with a fair unencumbered effort of propulsion, and without any necessarily great amount of slip. And if the average speed of rotation were to be taken as the basis of the account in calculating the slip, it is clear that a very large amount of apparent negative slip would be the result of the calculation.

A converse result would ensue were we to take a vessel with a perfectly fine run and thin stern-post, and fit her with a single-bladed propeller, having its shaft level with the surface of the water. Here one half of each revolution would be performed with the blade out of the water, the other half with the blade in the water, and under ordinary conditions of propulsion; for we might assume the run to be so fine, or the

screw to be placed so far astern of it, that, while the blade is immersed, it should be wholly disencumbered of dead-water action. The slip of the propeller, while submerged, might be of ordinary proportions; but the blade while out of water, having but the air to act on, would experience almost no resistance, and that part of the revolution would be performed with an almost unlimited speed. Under such conditions it is plain that the average speed of rotation would be quite in excess of that due to the progress of the ship through the water, and the apparent slip would be very large. In both cases the apparent slip would be altogether a fallacious indication of dynamic merit.

If, recurring to the ship with its screw-shaft placed at the ordinary level, we substitute a two-bladed propeller for that with a single blade, the conditions are not very materially altered, for one blade will be traversing the dead water below the shaft, while the other is traversing that above it.

The body of dead water encountered by the upper blade will, no doubt, be heavier than that encountered by the lower; but the shock experienced by each blade will be simultaneous, and the two retarding forces will co-operate. Here also, with certain proportions of blade, and certain mass and distribution of dead water, the retardation may be such as to exhibit apparent negative slip.

And although in proportion as the blades are multiplied, the inequality of re-action on which the result depends becomes sub-divided and distributed, so that, though each blade in succession encounter a separate shock, the circumferential stress on the shaft may become in effect uniform, and its rotation uniform also; yet it does not appear to be impossible that, with a three-bladed, or even with a four-bladed screw, the inequality should be such and the momentary retardation such, that apparent negative slip should ensue.

Practically, whenever the circumstances of the propeller are such that a sensible shock is experienced by the shaft in any part of its rotation, there exists a condition which must produce some inequality of motion, and the inequality may, under assignable circumstances, be such as to produce an appearance of negative slip.

The magnitude of the shocks experienced under ordinary conditions, notorious as it is to all who have voyaged in screw ships, is yet more surely exhibited by such dynamometric diagrams of propulsion as have been from time to time taken from the shafts of screw ships. Many of these are given by Mr. Bourne in his interesting work on the screw-propeller.

But, great as is the severity of the shock indicated in such diagrams, I believe that

the representation is in every case short of that which was really experieneed, because, in eonsequence of the inequality of force exhibited, it has been always found neeessary to control the dynamometric apparatus by a regulating oil cylinder or other equivalent contrivance; and I am inclined to think that the difficulties thus imposed on dynamometric trials, have been the chief reason why so extremely valuable and instructive a method of investigation has not been more steadily pursued.

But though dynamometric trials are, no doubt, for this especial reason diffieult, it would not be difficult to test the inequalities in the speed of the shaft's rotation by a suitable chronometric apparatus, and I am deeply convinced that most instructive results would be obtained by the use of such apparatus. It would at least serve to shew in what part of the propeller-rotation it happens that negative slip, when it appears, is actually developed.

It may be enquired, with reference to the view I have adduced, if the elementary causes to which negative slip is attributed thus almost invariably exist, why does negative slip itself not appear more uniformly? Why is its appearance so capricious?

It is partly an answer to this enquiry to say that the aetual slip is, probably in all cases, much larger than has been assumed, since the apparent slip is taken as the true slip, and this is always calculated from the mean speed of rotation, which is already converted into a fallacious index by the irregular retardations referred to.

Thus, this eause of apparent negative slip may, and probably does, always operate largely; but it is only occasionally, and under circumstances exceptionally favourable to its operation, that its result is large enough to more than neutralise the real, and to produce an apparent negative slip.

It should also be borne in mind that in all direct-acting double-cylinder engines there is developed a maximum, as well as a minimum, of circumferential force occurring once in each half revolution, and if the screw be two-bladed, special results will probably ensue, according as the period of maximum force occurs, when the two blades are in the dead water, or when they are in the free water.

I do not pretend to have analysed quantitatively the operation of the causes which I have been describing, so as to predict the circumstances under which the appearance of negative slip should result. The task would be extremely difficult. But I am confident, that each of the causes is, a *vera causa*, and that it actually exists and operates.

Whether there be other causes equally capable of producing the result, I do not pretend to say—but, so far as I can understand the question, I know of no other.

If my views be correct, they certainly shew forcibly the dynamical advantages of an arrangement which I have long advocated, and which I strongly urged in my Note on Professor Rankine's Paper of 1865. I mean the placing of the propeller, not merely abaft the rudder, but at some tangible distance clear of it.

If by keeping the propeller within the dead wood, or even close abaft the dead wood, we are of necessity involved in a considerable loss of power from its operation on the dead water, inducing the possible appearance of negative slip as an index of that loss—if, by keeping the propeller well astern, we free ourselves from this encumbrance, and at the same time bring the propeller into a position better calculated to realize the gain of power due to the utilisation of the dynamic value of the wake, there are at least tangible reasons for testing experimentally the value of the advantages which seem within our reach.

In that Note of mine on Rankine's Paper to which I have already adverted, I stated that by a series of small-scale experiments of my own, most carefully conducted, and witnessed by a self-recording apparatus, I had found that by shifting the propeller from its place within the dead wood to its most favourable position, a result more than equal to doubling the horse power quoted was produced.

But to try such experiments on a large scale is beyond the pecuniary means of a private individual; and I must content myself with the endeavour to explain why I think the arrangement advantageous.

That it would be attended with certain mechanical difficulties I do not deny. To carry a screw-propeller safely at some distance clear of the stern is no doubt a serious undertaking; but to me it seems that the extremely lengthened run and prolonged stern frames adopted in screw ships as ordinarily constructed, are but a clumsy and imperfect method of avoiding, in their coarser forms, the objections which I have been tracing. The cost and the overhanging weight of a stern lengthened bodily are, I am confident, greater than would be involved in some well-considered structure, adapted solely to the carriage of the shaft and propeller, while the benefits realised by the latter arrangement would be incomparably greater. If the Chief Constructor will kindly begin by having the revolutions of his screw-shafts chronometrically tested, I shall hope he may be tempted onwards to the other more formidable looking experiment.

ON THE RELATIONS OF THE SCREW TO ITS REVERSE CURRENTS.*

By Arthur Rigg, Junr., Esq., Engineer.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

The currents driven backwards by the screw present at first sight many difficulties; nevertheless they are regulated by laws simple indeed when considered separately, but exceedingly complex in their combined effect.

The commonly-accepted analogy of a screw working through water like a solid body, entirely fails to explain observed phenomena, and in point of fact renders them more obscure, while the earliest inventors of this propeller seem to have regarded it more correctly as an oblique paddle. This view removes every difficulty, gives a mathematical accuracy to investigations, and affords much valuable information; while the pitch theory furnishes no accurate data, and creates paradoxes.

The following simple diagrams penetrate to the root of the subject; and present no contradictions: they point out the defects or merits of any propeller with the same certainty that the indicator reveals the working of a steam engine.

Three illustrations are given of screws with different pitches, and as the construction of all the diagrams is similar, and many of the letters correspond, a description of Fig. 1 will include the rest.

A B is the blade of a screw, 15 feet 6 inches diameter, and 43 feet $4\frac{1}{2}$ inches pitch. F E represents an arc through which the blade passes. A corresponding effect would follow if the water be supposed to move from E to F, and this arrangement is more conveniently illustrated.

The water may be regarded as a solid or incompressible body, free to move in any direction; and as such would be reflected from F to L by striking on the blade A B;

* Received 13th March, 1867.

and give equal angles of incidence and reflection; therefore the lines E F and L F represent two equal and opposed forces acting simultaneously upon F. By completing the parallelogram E F L G, their combined action will produce the resultant G F; which represents both in direction and magnitude the work done by the screw blade in moving from F to E.

FIG. 1.

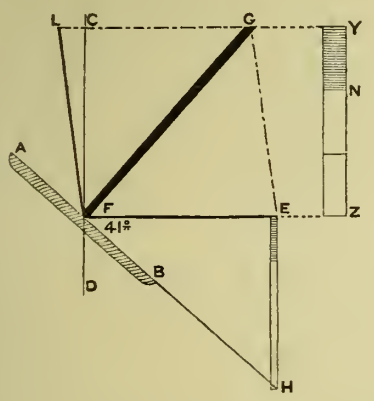


FIG. 2.

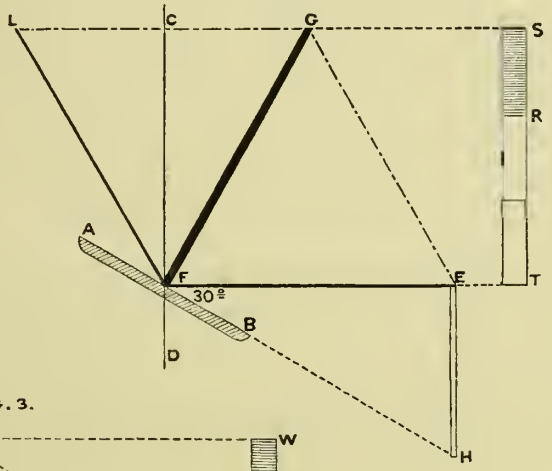
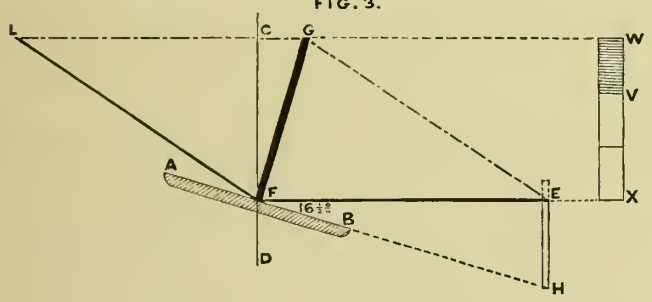


FIG. 3.



As, however, the ship travels only in the direction C D, this oblique resultant acts at a certain disadvantage. By again resolving G F into G C and C F, the former can only expend itself in giving obliquity to the reverse current; and the latter becomes the true comparative measure of the propelling power.

This vertical line is transferred to Y Z to avoid confusing the diagram; and it is divided empirically into three parts; two of which, N Z, are the ship's progress, corresponding with a reverse current measured by the third, Y N.

The entire circumference is nothing else than a succession of similar arcs; so that by calling F E its measure, N Z will be the ship's progress; and N Y the reverse current for one revolution of the screw.

An extension of A B to H, makes E H the pitch; and a comparison between both systems shews each to give a certain, though different, reverse current or slip.

Fig. 2 illustrates a screw 23 feet 6 inches diameter, and 43 feet $4\frac{1}{2}$ inches pitch. R T is the ship's progress during one revolution, and R S the corresponding reverse current. Taking the same proportionate division, the pitch E H will be found in this instance to coincide exactly with R T; seeming to give proof of the similarity of water to a solid body, while the case is no more than an accidental coincidence.

Fig. 3 is a similarly constructed diagram for a screw 23 feet 6 inches diameter, and 21 feet $8\frac{1}{4}$ inches pitch; and a good illustration of "negative slip." V X is the ship's progress, and V W the corresponding reverse current in one revolution. The same proportions are taken in this as in the preceding instances; but the pitch E H falls much short of the real advance made by the ship in one revolution of the screw. No paradox exists with this method of calculation, and the reverse current is determined with the same certainty as in the preceding examples.

The three instances given are taken at random, to shew the comparison between the system of calculation herein described and the common method. Although the separation of the lines Y Z, S T, and W X into three parts is made simply for convenience, and to render comparison easy, yet every screw and every ship has its own particular proportions; but the total is always constant, and though affected by other relations, it is a good comparison and affords the best starting point for accurate investigations.

It may be noticed, that the last screw, on Fig. 3, is that of the *Bellerophon*, but its negative slip was not quite so much as the diagram shews.

As there has been much discussion upon this subject, there is here appended a Table extracted from Mr. Reed's Paper of the 23rd March, 1866, giving a number of instances of negative slip; and the same screws calculated by the preceding method. The reverse current, &c., is taken only from the circumferences, and will have a smaller value than is shown by the Table. For comparison, it may be taken that the mean reverse current in each example is actually one-third of the amount at the circumferences.

[TABLE

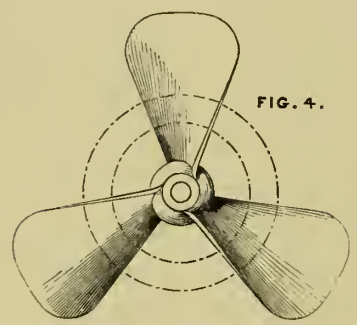
Table extracted from Mr. Reed's Paper on "Negative Slip," read before the Institution.					Calculations based on the foregoing Principles, by Arthur Rigg, jun.			
Ships' Names.	Diameter of Screw.	Pitch of Screw.	No. of Revolutions.	Ship's rate. Knots per Hour.	Ship's rate, per Revolution of Screw.	Total current through Screw, per Revolution.	Reverse Current at circumference, per Revolution, "Positive Slip."	Reverse Current at circumference, per Foot of Ship's Advance.
	ft. in.	ft. in.			ft.	ft.	ft.	in.
Archer	12 6	7 9	71	6·391	9·118	14·955	5·837	7·681
,, ...	11 7	7 9	73	6·151	8·53	14·793	6·263	8·810
Arrogant ...	15 6	15 0	55·5	8·295	15·14	27·923	12·783	10·131
Cygnet	9 0	10 6	104	10·827	10·54	18·912	8·372	9·531
Flying Fish .	13 1½	15 0	62	9·731	15·89	26·469	10·579	7·989
Hannibal ...	17 0	12 6	64·87	8·6	13·42	24·243	10·823	9·677
Miranda ...	12 0	11 6	87·87	10·75	12·39	21·602	9·212	8·921
Plumper ...	8 9¼	4 6½	136·25	Negative Slip. 18·43 pr. ct.	5·37	8·937	3·567	7·970
Simoom.....	15 11½	16 6	52·5	8·747	16·87	30·826	13·956	9·926

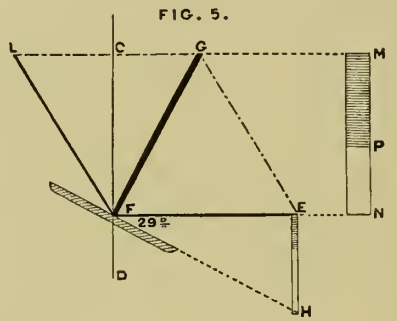
The "negative slip" in these instances, and indeed in any others which might be brought forward, is greatest where the inclination of the screw is smallest, thus entirely agreeing with the inferences drawn from the diagrams.

Returning again to Fig. 3, and assuming the water to be still on entering into the screw, its absolute velocity on leaving will be that of the reverse current V W; but the ship has advanced in the same time through V X, and, therefore, the whole distance, W X, will be the velocity of the water current passing through the screw. Let the arc F E now be taken for the space between two blades of a screw, measured circumferentially; and W X the distance travelled by the water as it is discharged from the after edge of each blade that passes over the space F E. During the interval between the departure of one blade and the arrival of the next, the current W X will not entirely lose its velocity. The leading corner of the following blade will enter a current, thus moving with a share of the velocity imparted to it; but the leading corner will have receded backwards by an amount measured by E H during the same interval. Now, if the current W X still retains enough velocity it will overtake and strike behind the leading corner with more or less force. Where the inclination of the screw is small, the effect is often observed by a honey-combed appearance due to the action of the unexpended force of the reverse current—this is not only a simple loss, but the power

wasted also hinders the ship's progress, and is undoubtedly a cause of diminution of speed which accompanies negative slip, as both circumstances are produced by corresponding arrangements.

In taking a practical example, all varieties of inclination of the blade are found combined in the same screw. At the circumference there will be a large reverse current compared with the ship's progress; approaching inwardly the current will gradually diminish, until at last there will be none; and at such a point the screw blades cease to propel, and are no more than obstructions to be dragged through the water.





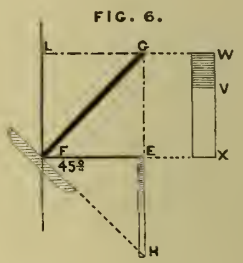


Fig. 4 illustrates a screw 10 feet diameter, and 17 feet pitch, making sixty-five revolutions per minute, and $7\frac{1}{2}$ knots per hour. Figs. 5 and 6 are the diagrams: Fig. 5 taken for the extremity of the blade, and Fig. 6 at a diameter of 5 feet 4 inches. For each revolution of the screw, this ship moves forward 11,692 feet; and the extremity of the blade gives a total propulsion of M N or 26·5 feet. With such a current it is apparent that the following blade will not provide enough clearance E H; hence the advantage of increasing the pitch, and cutting off the outer corners. At 5 feet 4 inches the whole current W X measures 17 feet, and the clearance E H is exactly the same. This diameter represents a very efficient portion of the screw blade, while within a diameter of 3 feet $8\frac{3}{4}$ inches there is no reverse current from this screw, and therefore no propelling power.

Both these circles are marked by dotted lines upon Fig. 4, and this screw is by no means the best for its purpose, but is given as a fair average example of common practice.

Before entering upon practical conclusions, it may be well to point out a simple rule for calculating the total current through the screw; namely, S T, (Fig. 2) when the angle of the blade is known at any required diameter.

E G is parallel to F L and E F is parallel to G L
and E F = F L by construction
∴ the line E G = E F
L F E G = 2 (L E F H)
S T = E F sin L F E G or E F sin 2 (L E F H).

From this equation is obtained the rule—

S T = circumference (E F) × sine 2 (L E F H).

In this particular case the circumference is 73,827 feet, and the angle of the screw-blade 30°.

∴ S T = 73,827 × sine 60°
= 63,934 feet.

And this result agrees exactly with the measurements of the diagram.

These principles readily decide the best form of propeller, and indicate the variations required to secure the maximum effect in different ships. The diameter of the neutral circle within which propelling ceases will greatly vary, and it must offer the least possible obstruction to the free passage of water by the blades being made parts of a true screw. From the neutral circle to the extremities each blade must be set at such an angle as, on the one hand, to avoid a loss of power by entering into a current moving more rapidly than itself; and on the other hand, to avoid any violence in displacement,—and each ship requires a separate consideration.

Perhaps, however, the most important point in the whole subject, is the actual direction in which the current is driven away from the blades of a screw propeller. Originally, the water obeys the resultant force G F; but is subject to a variety of disturbing causes from the screw itself, and also from the form of ship. The obliquity of this current, and also the disturbing causes, are both sources of loss of power; small indeed, under favorable circumstances, but always present, and a serious waste in slow vessels or against head winds.

In towing there is a loss of upwards of 20 per cent. in some cases, as the following experiment will shew. It was tried on a steam tug belonging to the Grand Junction Canal Company, and the indicated pull was seen from a spring dynamometer fastened to the bank. The first experiment was made with the screw alone, and the second with the author's patent deflectors, which recover the power wasted by the oblique currents.

No. 1, steam 70 lbs. Engine 240 revolutions. Tension $6\frac{1}{4}$ to $6\frac{1}{2}$ cwts.
No. 2, ,, 65 ,, ,, 230 ,, ,, $7\frac{3}{4}$ to 8 ,,

There were two deflectors in this experiment, but four would have given a higher result.

The principles herein described are the result of many experiments and theoretical investigations into the subject of screw propulsion; its inherent defects and their corresponding remedies. There are some points to make clear, and doubtless others to

be found out; for this outline stands only at the threshold of the enquiry. The principles herein described throw a new and clear light upon many obscure points, and never fail in assigning to their true cause phenomena which otherwise seem inexplicable. They are entirely opposed to existing theories; but they point out a sound practical rule for the avoidance of needless evils, and the utmost development of the capabilities of the screw propeller.

DISCUSSION ON THE THREE PRECEDING PAPERS.

Mr. MERRIFIELD: Perhaps I may add one or two words in explanation of Professor Rankine's Paper. Having reference to the motion of the water, he shews that the screw works with a forward motion, which is not simply due to the ship's progress, but is accidentally due to the forward velocity in the wave. On that subject I will remind you of a characteristic of wave motion in still water. If that (illustrating) be a portion of a wave in still water (*i.e.* without current), that wave only appears to move along, each particle of water simply describing a circle, and as at the top of the wave the particles are going forward, so at the bottom of the wave the particles are going backwards. I have watched this myself attentively. I have occasionally swum in a long rolling swell, and I have distinctly felt the pull back. Very well; now having settled what motion there is at the crest of the wave—that it is always forward, and that at the bottom of the wave the motion is always backward—apart from any motion that may be due to the water, that is to say, superadded to that subsisting in the sea, you will have this consequence, that while they balance one another on the whole, they alter the character of the motion at particular points. You have a wave not very far from the bow, due to the wave of displacement of the ship. You have then, in general, especially in long ships;—you have a wave here (at about two-thirds length from forwards,) in which the particles are going backwards, while a little further aft they are going vertically downwards; and then, at this point, (the stern-post) which is generally the point occupied by the screw, or possibly, even a little distance behind it, we have reason for supposing that there is an exceptional velocity not due to the following stream of water, but which is due to the wave itself, in which the particles of water are, owing to the motion of the wave, moving forward;—and Professor Rankine says, that that may account for any amount of negative slip. I will only add this observation of my own, namely, that that fact is rather confirmed by the observation that the crest of the wave is generally a little abaft the screw, and that some experiments on models show, that the best advantage, to which the screw can be worked, is when it is placed a foot or two, or even four or five feet, probably, on a large scale, abaft the usual position. That will account for any amount of negative slip; the actual amount of negative slip depending, not on the velocity of the stream, but on the character of the following wave.

Mr. E. J. REED: It would be hardly courteous, Sir, for me to allow the Papers of Professor Rankine, Mr. Froude, and Mr. Rigg to pass without a word or two of notice, particularly as they have all done me the honour of referring to my Paper of last year. I gathered from Mr. Froude that his view,—at least one of his views, for his Paper abounded in what I must say were original and valuable investigations, as to what actually goes on at the stern of a ship, in the neighbourhood of the screw; investigations which

demand much more careful consideration than they can possibly receive now,—his principal view, in so far at any rate as it affects my Paper of last year, was that we may look in the wake of the ship for the total momentum impressed upon the water by the backward action of the screw, or by the forward action of the ship, whichever way you please to put it; and I think from Mr. Merrifield's exposition of Professor Rankine's Paper, that that view reappeared there, and that Professor Rankine's view amounted to pretty much the same as Mr. Froude's, inasmuch as it was by virtue of the following wave, added to the drag-water, if I may so speak, that we found reappearing at the stern the total momentum impressed upon the water by the action of the screw, or of the ship. Now that is rather a startling view, and it certainly is one to which I am unable to assent at the moment. I do not mean to say that it is an untrue view, because I am not absolutely clear upon that point; but it certainly does appear to me that the dynamical principle which I ventured to put forward last year, might have been dealt with a little more closely than it has been; because it seems to me to be almost an axiom in mechanics, that the total momenta impressed by any force in one direction must be looked for in the form of equivalent momenta in the opposite direction. I do not yet see what becomes of all that momentum impressed upon the water by the bows of the ship. As Mr. Scott Russell has just well remarked to me privately, the breadth of the bow-wave, that is the wave raised by the forward motion of the ship, is much greater than the ship itself, and so is the breadth of the following wave; and it is difficult to see how a propeller moving within the limits of the ship's breadth, can take out of that following water the total amount of momentum generated in the forward direction. One thing comes out, however, very strongly from Mr. Froude's Paper, and that is the extreme importance of getting the screw as far as possible away from the dead water that follows the ship, and that is an important question; because, from the only statistics which we are able to deduce from the trials of steamships with the formulæ which we use, we do not find any encouragement to try to get away from that broad stern-post, and that following dead water, which must necessarily exist, and I think there are but few considerations which tend more to take from the value of our ordinary formulæ, than the fact that we find ships with broad stern-posts, and ships with next to no sternposts, giving pretty nearly as good constants as each other: the constants are nearly similar in both cases. However, Mr. Froude thinks it is desirable and practicable to carry the screw far away from the sternpost. This appears to me to be doubtful. I know this, that when you come to great power and high speeds—cases in which these considerations spring into enormous importance, far more than they do in cases of low speeds and moderate power—it then becomes very difficult indeed to get the point of application of your screw far away from its main supports, owing to the great lateral vibration which screws set up, whatever may be their form, and whatever their pitch. In point of fact, as in a very recent case—a case which I was discussing only yesterday with a very eminent marine engineer—I was very anxious to get the screw away from the dead wood, for a particular reason, and he strongly insisted that the difference between the transverse pressure of the upper and lower screw blades is so great that you cannot escape a very great lateral pressure, and the vibration, as we all know, is something formidable with a powerful engine. That that is the case I know from an experiment which was made by the late Mr. Joseph Maudslay. He had a small yacht with feathering blades, and in that case the excess of pressure on the lower blade, as compared with that on the upper, when both were in a longitudinal plane, was so great, that the vessel was turned round, and not only turned round, but turned round quickly, from no other cause than the excessive pressure on the lower blade beyond that on the upper. That only indicates what must be the amount of lateral action in the case of large screws driven at high speeds. I think, Sir, it would be paying but a poor compliment to

these able Papers, and certainly it would be very presumptuous on my part, to attempt to make anything like a complete answer to them, or to profess to do them anything like a full measure of justice on this occasion. I, therefore, can only say, that I will give them the most careful attention when they get into our hands, and if anything should appear to me to come out of them, either in support of or in contradiction to the Paper which I had the honour of reading last year, and which has not yet been answered to my satisfaction at any rate—if, I say, what does come out of them should appear to me to be valuable, I will endeavour to record it, and to place it before the next meeting, and I hope that that course will not be considered to be an improper one, because I believe that one of the strongest proofs of the value of this Institution, one at least of the principal causes of its value, lies in the fact that it has been the means of bringing very capable and very zealous minds successively to bear upon these abstruse problems associated with naval architecture, and I think that the succession of Papers which we have had on the rolling of ships, and the very valuable Papers we have had to-night as to the slip of propellers, will be amongst our most valuable possessions, and that they will be the means of establishing sound principles in the course of time; and I believe myself that it is only in the course of time that sound principles can be established on these extremely abstruse and complicated questions.

Mr. Scott Russell: I think, Sir, I can assure you that one of Mr. Froude's problems which he has been good enough to set before us to-night has been solved. He says to us—If somebody would only invent some way of setting out the screw a great way behind the stern-post of the ship, we might expect to have a great advantage from it. I thought so too; and I tried, what I venture to think now, as I thought then, is not a bad way of getting the screw a great way behind the end of the ship. The method was this:—Take this as the sternpost of the ship (illustrating on the black-board). There is the keel, and there is the bow. This, if you like, is the water line. Then, what I did was this:—I cut off at this point the keel of the ship. I made the ship very strong as far out behind the rudder post as I am now drawing. I then made this part of the stern of the ship, and I carried the screw shaft right out, in this manner, beyond the stern of the ship. I had there got my screw far clear of the rudder post of the ship. On this rudder post I then placed a rudder worked from the inside of the ship, the rudder post going up through the decks, or not, as circumstances might require. Here you had a screw a great way behind the rudder post; and it is quite true, I think, that in those ships I got some considerable advantage from so placing the screw, because I did what Mr. Merrifield has so well described. In that particular vessel I got the screw out into that part of the stern way where there is a great deal of forward motion, which I was then enabled by the screw to pick up and turn to account. So much for that. But, I am sorry to say, that though I thought that a very clever thing at the time, I now know that there is one that is a great deal cleverer, and a great deal simpler, and I will now shew it to you.

Mr. Mac Gregor: How much did the shaft protrude in that case?

Mr. Scott Russell: Out from the front of the rudder post, I should say six feet, and from the bearing three or four feet. But I will now shew what is a much simpler, and a much better plan, as far as the wave is concerned, for picking up the force, either of the wave or of the sea. Let this (illustrating) be the true stern, or rather the true rudder post of the ship. Let this be the place of the screw—the usual place. Then I have ascertained as a fact, and will venture to give it to you as an axiom, that there is a certain distance behind the midship section of the ship at which, for a given velocity, you can perfectly calculate where you will find the place of the crest of the stern wave. Now, if you will be good enough to

make the lines of your vessel extend back until the screw is placed under the crest of that wave, you will then have all the good that that wave can give you; and I need not tell you, that the place of that wave is a matter with which we are thoroughly acquainted, and which we can definitely point out. Now, then, if I do that, what are the consequences? A very simple diagram will show you what are the consequences. Take this (illustrating) as the midship section. Suppose that there is the usual bow wave, that then there is the usual wave behind that, and that there is the usual stern wave, of which we have correctly calculated the place. Then I may say that, if the water lines of the vessel be made so fine—be made so much longer than is absolutely necessary, as to place the screw in that wave—you then have all the utilisation which you can get out of that wave, and we know that exactly. Permit me to say, that I first found this out by making a vessel with the same length of bow and stern; and having made her of the same length of bow and stern, I was astonished to find—what I am not now astonished at—that the crest of the stern wave, instead of being at the stern, was a great deal before the stern, which simply showed that I had made my after-body too long. You have therefore to make your after-body sufficiently too long, so that the wave, instead of being clean out of the lines of the ship, shall be well within the lines of the ship over the screw, and you have solved that part of the problem. I had not the advantage of hearing the first part of Mr. Froude's Paper, which I am sorry for, but to prevent misunderstanding, I would merely say this—and I have no doubt that he said it—that the motion communicated to the water by the bow of the ship has been proved by experiments, and I fancy beyond all doubt, to pass so far away from the ship, and extend itself at so high a velocity through so large a sphere, that that part of the motion communicated to the water can most unquestionably never be overtaken by the sweep of the screw or by the stern of the ship. The ship itself makes a hollow in the water, which extends at the midship section of the ship far beyond the breadth of the ship; far therefore, also, beyond the sweep of the screw; and the following wave, which fills up that hollow, extends also far beyond the sweep of the screw; therefore those two waves—the wave of displacement of the bow, and the wave of replacement of the stern—extend over so wide a sphere, that the sweep of the screw can never reach them, and so much motion as is communicated to those two beyond the sweep of the screw, has gone into the sea, and is lost for ever. A portion of the power has, certainly, through the skin of the ship, given motion to a large envelope of water around the ship, and that subject no one has studied more thoroughly than Mr. Froude; and he can tell us, I have no doubt, as he once told me, how thick that skin is. I think I remember that at that time my observation upon some long ships and his calculation happened tolerably to agree. But there is one point which Mr. Bourne alluded to, and which I must allude to, namely, that nobody can tell what is the degree of closeness with which the water skin sticks to the after-body of the ship. *That* nobody has ascertained—neither what the peculiar nature of this skin-resistance is in the after-body of the ship; nor I am afraid can anybody tell, when the water which is moved by this skin comes to the midship section—whether this film of water in motion does keep adhering to the after-body, and following it, like a skin, into the wake, or whether it does communicate some of its motion to the surrounding particles, and pass off in that wide wave which we see following with the scum in the wake of the ship. I am afraid, I must say, that though I like these things, and have studied them now for thirty or forty years, this is a subject on which I am still very profoundly ignorant, and therefore although I say I am satisfied by close observation, that there is a large quantity of the force which had been applied to move the water in contact with the skin of the ship throughout the bow; although I know there is a large quantity of that which is picked up again with the run of the ship, yet I cannot say whether it is a very large proportion or a moderate proportion, and therefore I would entreat the Chief

Constructor of the Navy, and other gentlemen who have the power of making very exact experiments upon these subjects, to make their experiments as exact, as numerous, and as much to the point as possible.

Mr. JAMES R. NAPIER: Sir Arthur Cotton made experiments in India to discover the resistance of the skin of different parts of the vessel: he covered the bow, bottom, sides, and stern of a painted wooden vessel, with smooth brass, and got certain results with each addition. The only result, however, which I remember, is that the covering of smooth brass at the stern did not reduce the resistance of the vessel as it had done when applied to the bow, bottom, and sides. The experiments might be had for publication in the *Transactions* of the Institution.

Mr. GALLOWAY: This subject, Mr. Chairman and Gentlemen, is an all-absorbing and an all-important one; and I may say that for very nearly ten years it has occupied my attention. Ten years ago I represented to Mr. Lloyd, the chief engineer of Her Majesty's Royal Navy, a new form of screw propeller. He asked me my reasons for supposing that that form would be better than the then existing form in use. After I had given him my reasons, he complimented me upon being theoretically right. I thanked him, and submitted to him that if I was theoretically right, I could not by any possibility be practically wrong. Now, there are many theories; but an ounce of fact is better than a ton of theory. There must be something radically wrong in the present application of screw propellers; and I submit that there is not a truly correct screw in Her Majesty's Royal Navy. I say, secondly, that you never will get a true practical result from a screw propeller, as such, until you just place one blade behind the other instead of having them as you have now, and then you will have a true screw. It is a lamentable fact, mentioned in Mr. Rankine's Paper, that the best screw in use loses about 25 per cent. I believe I am stating it rightly. In conclusion, I mean to say this: increase the speed of your screws, reduce the diameter, twin screws will give the best results for all practical purposes, then apply the power properly, and with a little ingenuity, that is to say, have no extra weight, and you will get a much better result than you have at present.

Mr. JORDAN: I do not think that the speed of the screw is rightly ascertained in practice. I think if you could ascertain the speed of the screw, that would also give you the positive slip. I believe that negative slip has never existed in any case or under any circumstances.

The CHAIRMAN: Mr. Froude has made some observations about an officer going down to bathe in the screw well. Let me tell you that it is not requisite to go into the screw well; for, in 1815, when I belonged to Her Majesty's ship *Malta*, which had a very round counter, we constantly kept a stern ladder attached to the stern port, and I was in the habit, while the ship was going 6 or 7 knots, of bathing in the dead water close home to the stern-post. On one occasion I caught hold of the rudder chain, when I thought I might have been washed out into the wake, but drew myself into the stern ladder again. Frequently we were followed by pilot fish, and it is very seldom indeed that any man can hook a pilot fish, but I was determined to obtain one of these to preserve as an object of natural history. I used a very slender fishing rod, with a hook attached to a line about 6 inches long, and passed it down beside the ship's stern-post, while she was rapidly running through the water, and I literally put the bait into the mouth of the fish, hooked, and took him, so that the resistance of the water, running past the ship there, was nothing. It was, in fact, dead water. I took that fish, but his companion left the ship, and was unable to regain us by reason of going out into the wake. Some observations have been made as to the wave about the counter. I think every seaman here will understand that whenever a ship is sailing without having a screw attached

to her, and a roller breaks in, it breaks in about the third or fourth port from aft, under the main channel. The crest of the sea is there, and when you come to the question of having only 6 inches between your keel and the bottom, you will find that a very heavy roller will roll in and over on deck. With reference to elongating the screw, I may mention that a very awkward occurrence happened on board the *Phœnix*. When she was coming home she was pitching heavily, and going about 9 knots: she gave a sudden jerk, and bent the screw-shaft in-board, and nearly destroyed the vessel before we could stop the engines, so that it is not quite safe to elongate the screw, or to carry it any undue distance from the stern-post.

Mr. BOURNE: Perhaps you will allow me to make a few remarks upon Mr. Froude's Paper, which contains the most philosophical explanation of the phenomenon of negative slip that I have ever heard. I think it is a real ground for congratulation to this Institution that we should have an opportunity of listening to such a Paper. With respect to the observation we have heard as to the difficulty of extending the screw beyond the rudder—why, it is very well known that a great many vessels have been built upon that principle. I remember a good many years ago a ship being built at Port Glasgow —the *Frankfort*—and there the screw was projected through the rudder, and that vessel certainly obtained a very superior performance. Her co-efficient of performance was superior to that of any vessel of that day; not only was this the case, but that vessel was totally devoid of vibration. The effect of having extended the screw beyond the stern was to take away the whole vibration from the ship. That was another advantage. I think I understood Mr. Reed to see a difficulty in this circumstance, that when a screw is put in motion two effects are produced—one is to send the water aft, the other is by means of the bow wave to send the water forward, and, action and re-action being equal, I think I concluded that there was a difficulty in seeing how it was that there could be any negative slip at all. The most beneficial action that could be produced, it was contended, would be that there should be no slip—but it was difficult to see how even this could occur. Now, I can see no difficulty at all about that case. It so happens, that the current of water which is sent backwards from the ship does not flow backwards with nearly the same velocity as the film of water moves forward that is carried by the ship; and in fact, in the existence of those two opposite currents, one proceeding backwards with small velocity, the other proceeding forwards with a large velocity, we have undoubtedly action and re-action equal—in so far as we have an equality of pressure; but the amount of *vis viva* in the film of water adhering to the ship is far greater than that in the column of water projected from the stern of the ship. I believe it is pretty well admitted, as I stated to-day, that about nine-tenths of the power of the engine which is expended in propelling the ship is expended in friction, by the bottom of the vessel rubbing against the water, and so putting it into motion. There must be a very large amount of *vis viva* in the water so moved, and you have two opposite columns of water, one possessed of much more *vis viva* than the other. In the action of the ship we have an action very analogous to that of a cannon ball projected from a cannon. In the gun there is the same pressure urging the gun backwards that there is urging the ball forwards, but we know that in the gun there is very little *vis viva*, because it moves through a very small distance, whereas there is a greater amount of *vis viva* in the shot, because it moves through a very large distance. If the film of water which moves with a high velocity be translated, as Mr. Froude has explained, into a larger quantity of water by rubbing upon it and putting it into motion, you then have two volumes of water, one with a larger amount of *vis viva* than the other, and I think that this circumstance would explain the phenomenon of negative slip itself. It is said that this indicates momentum. But what is the difference between the momentum and the *vis viva?* What is the amount of mechanical power in the moving water?

That is the whole question. There is so much power in the water moving forward, and so much in the water moving aft. Which has the preponderance? If the balance is in the water moving forward, there is no difficulty at all in seeing why there should be negative slip. In fact, the difficulty is in seeing why there should not be negative slip more frequently than there is, and I believe one reason why there is not, is that there is a great deal of lateral slip—not retrogressive slip merely, but lateral or rotative slip, and this makes the slip positive that would otherwise be negative. But upon these points I need not dwell. I only wish to tender to Mr. Froude my thanks for the information we have received from his Paper, and which I think we must all value.

Mr. COWPER: I beg to add one or two words in reference to the observations that fell from Mr. Reed. I cannot quite agree with him that the question is that of taking up the WHOLE POWER that is impressed in the moving water. Of course part of the power of the engine is given first to the water in front of the bow, and part also is given to the water that is in contact with the ship, by the skin of the ship moving the water forward; therefore that water contains the power you have exerted, and if that water could be concentrated by any means into a cylinder at the stern of the vessel, you would then be able by a screw propeller to take out a large proportion of that power, and the screw might be going at only half the speed of the ship, because it would be working in water that was going at more than half the speed of the ship. I think that is easily understandable in this way. Suppose a screw is going at a certain speed which will give a *certain forward* PRESSURE on the screw-shaft, and it is *that pressure* which you wish to maintain, it is of no consequence, as far as the driving of the ship is concerned, what that screw is getting its resistance from—whether from water in motion or anything else. When that screw presses against the water it meets with a certain resistance and it will propel the ship. If it is going at a certain rate in water in a state of rest it will create a certain pressure, but if the water is running backwards, the screw must go faster to create the same pressure, but if the water is going in the same direction, the screw need not turn so fast to create the same pressure; therefore you may obtain the force on the shaft sufficient to drive the ship, with a less velocity of screw than the speed of the ship—if the water is following behind, that is to say, you may have fewer revolutions than the speed of the ship, or negative slip; because the screw is turning in water which gives you more velocity with a less number of revolutions.

Mr. GRANTHAM: I would say a word upon a practical point which has come out in this Discussion, and that relates to the screw being placed far aft in the ship. I have had myself an opportunity of seeing this question tested on a small scale. I cannot speak with any very great accuracy, but only from general observation upon the subject. I had the pleasure of being in the trial-trip of the very vessel which Mr. Bourne has named—the *Frankfort*, and in which he says a high result was obtained. Certainly there was a high result obtained. I am not aware whether any accurate experiments were tried to ascertain the real result as regards speed, but I know that this vessel came out with very large boilers, which were not common in those days, and I recollect perfectly well that we ascribed the very high results obtained in that instance to this fact. I am not aware that any minute or accurate investigations were made to ascertain what was the real result, scientifically, of that experiment. I am only aware of this, Sir, that several vessels were afterwards built with the screws placed in a similar position—astern of the rudder-post.

Mr. FROUDE: How far, may I ask?

Mr. GRANTHAM: The rudder was placed, I suppose, where the screw now is. They changed places.

Mr. FROUDE: Clear of the body of the ship? What I desire is—for a line-of-battle ship, 12 or 14 feet.

Mr. GRANTHAM: No, not so much as that. They changed places, and the screw was put clear, of course, of the ship. There was no action from the water upon the rudder; it went clean away. Well, Sir, I have been in several vesscls—two or three I have superintended myself upon a large scale—built upon this plan, and I must confess that we had vibrations. With respect to the relative amount of the vibrations it is most difficult to speak accurately, and for this reason, that there is a very great difference even when screws are placed in the ordinary position before the rudder; therefore, to speak dogmatically, and say that all vibration was removed, or greatly reduced by the change of position, is perhaps saying too much, but my own conclusions were that the vibration was not reduced so much as I expected it would have been. Those vessels in which I was on board certainly had a great vibration, much more than I expected. There are practical difficultics, and the whole question, perhaps, is this—that in our merchant ships we found it extremely inconvenient to have the screw so placed as to be continually knocking against pier-heads, and things of that kind, and for that reason, rather than for any other, we abandoned it, or rather we made no progress with it. Several have been built by a gentleman who knew a great deal about this question. Whether he will agree with me in my opinion or not I do not know, but my own conclusion is that there has been no result sufficient to compensate for the positive inconvenience resulting from this style of building ships.

Mr. FROUDE: Were the revolutions of the screw increased in number at all; do you happen to know?

Mr. GRANTHAM: They were all merchant ships that I was acquainted with, and I never had any means of making accurate comparisons, such as have been made since. It is five or six years since I was on board of them. The vessels were not tried over measured ground with any degree of accuracy.

Mr. DUDGEON: Will you allow me to speak for one moment? I have constructed between twenty and thirty of these vessels with the screw outside the rudder, and in every one of them we did get, certainly, but one half the vibration. In all cases we got a very much better speed than we got in the ordinary screw. I have letters in my possession from captains and engineers, and everybody connected with them, expressing the highest satisfaction with the results that were obtained by those vessels with the screw outside the rudder. In one letter I recollect an expression which was a remarkable one. The writer says, "Sir, we steered like a straight-edge." The action of the screw behind the rudder is so perfect, when properly constructed, that the rudder is positively not required. The only time, as my friend has just observed, when any difficulty was found, was when we had to put the vessels astern in close water. In going ahead, the moment the vessel was under way, the screw shewed its natural power, and the rudder had the less amount of work to do. I found out that the screw behind the rudder was the best, the twin-screw being, in my mind, only a better application of the screw behind the rudder.

Mr. FROUDE: First, as regards the doctrine that a ship's resistance is chiefly due to the waves she creates, not to the currents she puts in motion, I am afraid I must confess myself a great heretic. I do not believe that the large wave which accompanies a ship in her progress, when put in motion, expresses any material share in the continued resistance she experiences. It is a phenomenon of establishcd motion, which, when once established, accompanies the ship without demanding much, if any, additional force for its maintcnance. I believe that however far ahead or astern, or on either side of the

ship that wave may be, it nevertheless tends almost or wholly to perpetuate itself. The wave created by a ship is partly a plus wave and partly a minus wave. If the speed be moderate the minus wave swallows the plus wave, the parallel crests wasting themselves laterally in but a small degree. Therefore, though its continued maintenance requires some force, I believe that the amount of force is very small. In fact, I believe that, practically, almost the whole of the resistance experienced by the ship, is of the nature of "skin-resistance." I have not myself even endeavoured to follow, mathematically, Professor Rankine's able investigations of what he terms "Stream lines," and I do not know whether the equations shew that under any circumstances the stream line action alone could leave the particles of fluid which a body has passed through, with progressive motion impressed on them; but his results prove, in particular cases, and suggest as a general conclusion, (to which I believe other investigators also have been led,) that in a perfect fluid, after the transit of the body, the particles remain at rest, the motions possessed by them during its transit being transferred from particle to particle along the line of motion, the established state of motion thus keeping pace with the body, which, therefore, when once set in motion, should continue to move without resistance; there would be longitudinal motion impressed upon the water by the action of these stream lines after a body has passed through them on the surface; but I do know this, that his theory goes to this extent—and I believe others besides Professor Rankine have followed out the same theory—that the motions which accompany a body in a pure fluid are motions which will reproduce themselves, and that except for the friction of the fluid against the sides of the body, the body, when once put in motion, would continue to move without resistance in a pure fluid. But since, in such fluids as we deal with, friction and many other imperfections are inherent, the moving particles rub against the sides of the ship, and rub against each other, and much longitudinal force is created, which, so far as I see, must be wholly expressed by a current following the body, which has passed through it and experienced the resistance. Whether the particles are pushed forwards or pulled forwards, or rubbed forwards, or in whatever way it is that they receive their motion, the force that is exerted on the particles must be exactly satisfied by the momentum of the particles when put in motion. That is my view of the wake—that with the exception of such amount of force as is consumed in the wave making, and which I regard as small generally, the wake expresses the whole force consumed by a ship in her propulsion, and in the same way the propeller, whether it be paddle or screw, necessarily shews a sternward current of precisely an equal momentum, and the currents when brought into collision, or forced into collision, strictly neutralize one another as far as progressive motion is concerned. The screw, while operating on the wake, gives its whole motion to the particles most near to it, the motion becoming distributed by degrees throughout the wake in a screw-driven ship, and there ultimately remains only circumferential, not progressive motion. If you look at the wake of a ship driven by a screw in still water, without any adverse circumstances, it shews neither progressive motion nor retrogressive motion, but only that independent circumferential motion which the screw has impressed on the particles. But if the screw-propeller in a vessel overcomes a resistance represented not only by her own wake, but by that of another vessel which she is towing, or if the resistance of a head wind be added to her own, then it throws distinctly a sternward current, and I am satisfied that any extraneous resistance whatever impressed on the ship will cause a sternward visible current in the wake. I have watched it dozens of times. Again, a very small amount of auxiliary canvas given to the ship will cause her to drag a wake after her; that is to say, as part of the resistance is overcome by the propulsive effort of the sails, her wake, which represents her whole resistance, is more than a match for the current thrown by the screw-propeller, which only represents a part of her resistance.

Now with reference to the effect of the following wave upon the ship. As far as I know, that wave keeps its place in the ship in all velocities. I will not say it holds the same place in every ship, but it seems to keep its place whatever the velocity is. No doubt if the vessel has very good lines she will bring the wave forward; if she is very abrupt, the wave will probably be far on her stern, but for any given ship the wave keeps in the same position. But, if I understood Professor Rankine properly, I think he said that although the screw gains an advantage in propulsive force by operating on that wave, wherever it may be, yet it also gives a factitious resistance in the ship in doing so, that is to say, it removes a part of that wave of replacement by which the water renders back to the ship the force which the ship had impressed upon it. As far as I understand the matter, I should judge that in driving back the forward motion possessed by that wave we were precisely doing no good,—that we were not only giving more effective reaction to the screw, but that we were also to an equivalent degree enhancing the ship's resistance, and that the circumstances would belong to the class of phenomena which I have called "dead-water," the dispersion of the dead-water throwing a great reaction on the engine, but producing no corresponding advantage in the propulsion of the ship. Now, with reference to placing the screw clear of all that motion about the stern, described as dead-water, and allowing it to operate on the wake alone—it seems to me that by placing it clear of the ship we gain two advantages. We operate on the wake where it is no longer a narrow, concentrated, violent current, but where it is a wide, open, and roomy current, possessing the same momentum as before, its reduction in velocity thus corresponding with its enlargement in volume; we operate upon the wake where it is a large and diffuse current, and not a localised current, and therefore we can operate upon it more diffusively. We get rid altogether of that mischievous action which I call the "dead-water action." Secondly, Mr. Reed has said, and I was very much struck with the remark, that Mr. Maudslay's screw steamer, when the blades were fore and aft, and the screws were allowed to rotate, showed distinctly by the course she steered that the lower blade was the one that received the excess of force; but I think when the screw-blade is not set fore and aft precisely the opposite effect takes place. The heavy mass of dead-water is collected round the upper part of the stern, and as far as I know, it is the upper part and not the lower that receives the excess of pressure during propulsion. I shall be very glad if Mr. Reed will correct me if he has distinct evidence to the contrary, but as far as my experience goes it is the upper blade and not the lower.

Mr. Reed: It was the lower in this case, I believe.

Mr. Froude: No doubt, because the screw was not pushing sternways. It is not more difficult to push sideways the water which is keeping pace with the ship, than it is the water which the ship is leaving behind her; in fact, it is less difficult, because as everybody knows, the fluid pressure on a surface due to a given amount of flatways motion is enhanced in proportion as edgeways motion is superadded; and this under the circumstances would tell chiefly on the lower blade, but during propulsion, I believe the upper not the lower blade receives the excess of force. I know that in the *Encounter*, a ship in which I cruised, this was always the case; and when, at Athens, the screw was unshipped to examine the bearings and readjust them, the after bearing was cut in the upper brass; the top blade of the screw had been perpetually tilted forward, striking the shaft end against the upper brass. In the little model I referred to, which was about three feet long, which I fitted with a screw-propelling apparatus, driven by clockwork, and which recorded everything it did—the number of revolutions, the distance of each

revolution, the speed, and everything else—in that I found most distinctly, that the upper blade was the one which had the preponderating force. The model was left to itself, and steered itself round in a curve, sharp in proportion as the screw was in close to the dead water of the ship. When the screw was at a considerable distance, I will not say it steered like a straight edge, but very nearly so; and I say, as was said just now by these Gentlemen, that the shock is produced by that very circumstance, that the screw is close to the stern. If you remove it from the stern, you remove it very largely from that unequal action of the two blades by which the shock is created. If there is an equal shock on the upper and the lower blade, there is no upward wrench on the shaft, there is no kicking action; but if the action of the upper blade produces an excess of force, the shaft is driven sideways and upwards, the blade is driven sideways and forwards, creating a shock which involves a great loss of force, and which I say is inherent in the screw-propeller when working in the dead water.

In reference to the possibility of negative slip, as arising from operating on the wake; I think it is very likely part of what I said in my Paper was not sufficiently clear. I wish to make it more clear, that the propeller, while it stops the wake, if it be theoretically perfect, will not be so speeded as to be virtually stationary in the wake, but will be receding before it (*i.e.* slipping negatively) with a mean velocity equal to half the speed of the wake. If we intercept the wake by a close succession of flat planes intersecting its whole track at right angles, each of these when it begins to operate as a perfect propeller should have a forward velocity equal to that of the wake, and pressing against its share of this moving mass, should bring it gradually to rest, operating on it as a pure retarding force. And on the principle that a body travelling with a velocity of 32 feet per second is wholly stopped in a second by a force which meanwhile recedes 16 feet before it, it will happen that the retarding force of the imaginary perfect propeller will have a mean forward velocity, or negative slip equal to half of the velocity of the wake.

The CHAIRMAN: I think, Gentlemen, you will agree with me in giving our thanks to Mr. Froude for his very interesting and able Paper, and also to the other two Gentlemen whose Papers have been read—Professor Rankine and Mr. Rigg.

NOTE ON THE DISCUSSION: BY PROFESSOR RANKINE.

Not having been present at the late Meeting of the Institution of Naval Architects, I beg leave to offer the following observations upon the Discussion on "Apparent Negative Slip."

I am sorry to find, from some of the remarks made in the course of the Discussion on "Apparent Negative Slip," that my Paper has been to a certain extent misunderstood. In particular, Mr. Reed appears to have supposed, that I controverted the leading dynamical principle of his Paper of last year; whereas I entirely concurred in it. Mr. Reed represents me as having said that "it was by virtue of the "following wave added to the drag-water, so to speak, that they found re-appearing at the stern the total "momentum impressed upon the water by the action of the screw, or rather of the ship." What I did say as to the motions of the particles of water in the following wave, was in these words:—

"The velocity of those reciprocating motions is not connected directly with the resistance of the "vessel—in fact, their resultant momentum is equal to nothing; and it is only the momentum of the "uniform current which remains after the wave-motions have died out that is equivalent to the ship's "resistance."

Mr. Reed said further, that "the dynamical principle which he had ventured to put forward last "year might have been dealt with a little more closely than it had been, because it seemed to him to be "almost an axiom in mechanics, that the total momenta impressed by any force in one direction must be "looked for by equivalent to re-appear in inverted momenta in the opposite direction." Now the whole of my Paper is founded upon that very dynamical principle to which Mr. Reed refers, in combination with another principle as to the oscillatory character of wave-motion.

Glasgow University, 22*nd April*, 1867.

ON TRIALS OF STEAMSHIPS AT THE MEASURED MILE.*

By E. J. Reed, Esq., Chief Constructor of the Navy, Vice-President.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

Nothing is more common now, in connexion with steamship performanees, than to hear the usual system of trial at the measured mile condemned as unfair, deceptive, and inferior in every respect to a more prolonged trial at sea. We scarcely ever attend a steamship trial without hearing this opinion freely expressed; it frequently takes the form of a newspaper paragraph, and I have even seen it stated in official documents by responsible persons.

Now, in order to satisfy ourselves whether this popular opinion is sound or not, it will be necessary to consider what are the objects with which the measured mile trial is undertaken, and whether those objects may or may not be more satisfactorily accomplished by other means.

In discussing the first of these questions, it must be borne in mind that the measured mile trial has, for convenience, come to fulfil objects for which it was not, I presume, resorted to in the first instance, and which could certainly be as well effected by a sea trial. Among these objects, I may mention the testing of the thorough efficiency of the boilers and engines when pressed to the full extent of their capabilities; the examination of the hull of the ship when subjected to the extreme power of the engines, with the view of ascertaining if any weaknesses or leakages exist; the examination of the connexions of the hull and the engines, such as thrust blocks and other bearers, and the various steam and water-pipes which are more or less intimately attached to the hull; and the trial of the draught to the boilers, and of the ventilating arrangements of the engine and boiler rooms generally. All these objects may, I think, be accomplished very satisfactorily on a continuous full-speed trial of several hours away from a measured mile; in fact, the test at sea would be more searching and thorough—in the case of the connexions of the engines and the hull, for example—when performed at sea than it can be when performed in smooth water only.

* Received April 11th, 1867.

The primary objects of the measured mile trial are not, however, those which I have already named, but these, *viz.*, the determination of the maximum steam power of a given ship's engines, and the true speed of the ship under the propulsive action of that power; and the determination of these facts under conditions which can be repeated in other ships, in order to afford scientific comparisons between them. The measured mile is also resorted to when the respective merits of different forms of propellers have to be tested; and, generally, whenever exact comparisons have to be drawn between the performances of steamships under like *external* conditions.

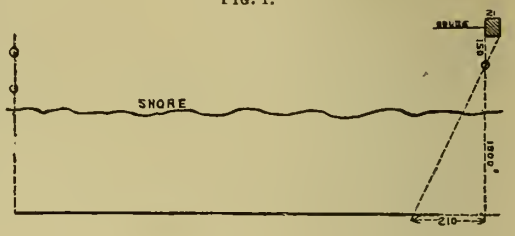
Now I, for one, cannot for a moment admit that a prolonged sea trial is better adapted, or so well adapted, as a measured mile trial for accomplishing these objects. On the contrary, I believe that if the latter system of trial were to be replaced by the former, we should be left utterly without the means of making satisfactory comparisons between the performances of different ships, or even between the performances of the same ship at different times; and I am of this opinion because it appears to me evident that in the sea trials you must of necessity be subject to most of the disadvantages and derangements of the measured mile trial, together with another set of disadvantages and derangements peculiar to the trial at sea.

The objections to the measured mile trial are, I believe, these: it is presumed that the short duration of the runs upon the mile with intervening periods, usually of longer duration, affords opportunity for what is called "jockeying," in more ways than one—the chief way being that of "bottling up" the steam when off the mile, and letting it into the cylinders at full rush when on the mile; it is presumed further that the method of defining the length of the mile by the transit of posts or other objects on the land affords opportunity for deception; that the tides are likewise made available for increasing the apparent speed, especially in rivers; and, generally, it is alleged that the speed obtained on the measured mile in no way represents the actual steaming capabilities of the vessel when on actual service.

Now in dealing with these objections, it is necessary that we should very carefully discriminate between the use of the measured mile and its abuses. I freely admit that it may be, and very often is abused, and made the means of securing for ships an utterly undeserved reputation for speed. To so great an extent are its abuses sometimes carried, that I have seen a vessel whose maximum speed was 9 knots, tried in such a manner as to secure an apparent speed of 11 knots, and have seen her announced in the newspapers of the next day as having attained the latter speed. On one occasion I observed, in addition to the "jockeying" below, the open—I may even say the barefaced—resort to three obvious sources of falsification. These were: 1, the running of the vessel in the full strength of the tide when going with it, and near the shore in slack

water when going against it: 2, the deduction of the average speed from an odd number of runs, of which the larger portion were made with the tide; and 3, the bringing of a wrong object on as a mark for the mile. This last device will be understood when I explain that at one end of the mile the marks were two posts, at the other end a post brought on with the side of a house; and the "dodge," if I may so call it, consisted in bringing the post on with the wrong side of the house. I have not the dimensions and distances involved, but it is easy to see from a diagram, Fig. 1, how the mile may be shortened by these means.

Fig. 1.



Presuming the breadth of the house to be 21 feet, the distance from it to the post 150 feet, and the average distance of the vessel from the post 1,500 feet, you will at once see that this device shortened the mile by 210 feet, reducing it from 6,080 feet to 5,870 feet. A speed of $10\frac{1}{2}$ knots would thus be made to appear 11 knots from this cause alone.

The other two modes of securing a high nominal result, *viz.*, those of using the tide as a source of speed, and the employment of an odd number of runs, are so manifest to every spectator that one almost wonders they are ever resorted to. But they are resorted to, nevertheless, and if I were not anxious to avoid giving personal offence, I would mention cases in which results that have been trumpeted to the world as extraordinary successes have been secured by these means. And even more than this may be said; for I was informed not long ago, on authority in which I place implicit confidence, that in the case of a very fast steamship the announced result was obtained by selecting three runs out of several—two with the tide and one against it,—and even this one run against the tide was somehow brought out much higher than any other of the runs in the same direction.

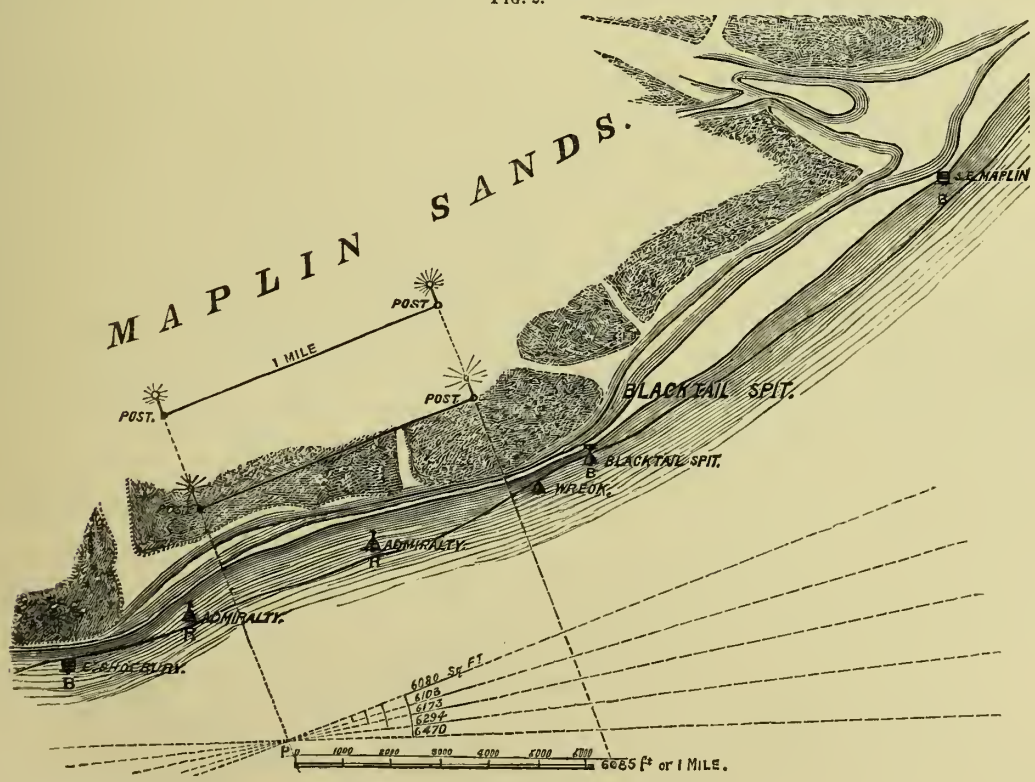
Now let me say once for all, and without the least apprehension of effectual contradiction, that no one of these last named causes of error can enter into the official trials of H.M. ships under the system upon which they now are, and for long have been, conducted. Those trials are carried out by a number of perfectly independent officers of the Royal Navy, who have no responsibility whatever for the vessel as far as regards her success or failure, who act under definite instructions, who record every result, and who report the results in full detail to the authorities at Whitehall. The standard miles are measured and marked by hydrographic officers; the exact nature of the marks is well understood by all on board, and the trials are usually attended by gentlemen of the

press, whose observation of the proceedings is very close, and who are not usually slow in detecting errors in official operations.

On the other hand, there are sources of error that cannot well be avoided, which operate against the full success of vessels, the trials of which are so conducted. It is indispensable to the complete success of such a trial that the vessel should come in to the mile with her fullest speed; that that speed should be maintained throughout the mile: that the shortest line between the mile-posts should be run; and that the vessel's course upon the mile should be maintained without the use of the rudder. Any departure from either of these conditions must result in putting the apparent speed below the real speed; and it is obviously very difficult indeed to avoid a departure from some one or more of them during a prolonged trial of, say half a dozen runs. The necessity for entering upon the mile at full speed, for maintaining that speed throughout the run, and for avoiding the resistance of the rudder is obvious; but I have found the necessity of running on the shortest line between the marks so ill appreciated, that I will trouble you with a few words upon it, notwithstanding the exceeding simplicity of the subject.

We have here, Fig. 2, a diagram of the measured mile at the Maplin Sands.

FIG. 2.



Supposing a vessel that has to run the mile to enter upon it at the point P, going eastward, it is obvious that, in the absence of corrected compasses and a proper prescribed course, and in the absence of marks ahead and astern, she may run upon one of an indefinite number of lines passing through that point, and intersecting the lines through the mile-posts. But it is easy to see that only one of all those lines, *viz.*, that which is perpendicular to the post lines, is exactly a mile in length between those post lines; every other line is longer than a nautical mile.

A line inclined at 5° to the true line, for example, is longer by nearly 8 yards; one inclined at 10° is longer by 31 yards; one inclined at 15° is longer by 71 yards; and if the angle be 20° the increase of length is no less than 130 yards. A very simple calculation will shew that a vessel which is really steaming at 14 knots will appear to be steaming at 13·94 knots, if running on the line inclined at 5° to the true line; the 14 knots will be reduced to 13·71 if running on the 10° line, to 13·52 knots if running on the 15° line, and to 13·15 if running on the 20° line. Now, at the very important mile at Stokes Bay, there were no marks whatever to define the true course of the ship (except in the clearest weather, when certain distant objects were visible) until recently, when the Admiralty, at my earnest request, laid down suitable buoys, which answer admirably. The measured mile at Plymouth is still deficient of these valuable guides.

It would be easy to shew that in observing the transit of the poles or other objects, great delicacy of observation is necessary when any important trial takes place. Such trials are, in fact, as I frequently have occasion to observe, not trials of knots, but trials of fractions of knots; and these turn upon a few seconds more or less. This is really a very important point, and one which is too little considered. It is often of great moment that a ship should attain a defined speed in knots. In the case of the *Bellerophon*, for example, it was very satisfactory to me, and to persons of much more importance than myself, that a speed of 14 knots should be attained. The actual average speed attained was very nearly $14\frac{1}{4}$ knots, represented by an average run of 4 min. 13 sec. on the mile. Now a difference of only 5 sec. on the runs would have put the speed below 14 knots, and slight as the deficiency would have been, amounting to five-hundredths of a knot only, it would have been ample for one's rivals and enemies to have raised an outcry about. They have often done so on less grounds; that is, on none at all. At low speeds, a second or two are of much less importance. At very high speeds, the seconds are all in all. To enforce these I will give a figure or two:—

At a speed of 6 knots a loss of 54 seconds would only occasion a loss of $\frac{1}{2}$ a knot of speed.

At 7 knots the $\frac{1}{2}$ knot would be lost by a loss of 39 seconds.

At 8 knots the ½ knot would be lost in 30 seconds.
„ 9 knots it would be lost in 23 seconds.
„ 10 knots, in 18 seconds.
„ 11 „ 15 „
„ 12 „ 13 „
„ 13 „ 11 „
„ 14 „ 9 „
„ 15 „ 8 „
„ 16 „ 7 „
„ 17 „ 6 „
„ 18 „ 5 „
„ 19 „ 4 „

These considerations shew how necessary it is to conduct the measured mile trials of steamships not only with impartiality, but with great care if truthful and scientific results are to be obtained. Before quitting this part of the subject I must, however, submit an observation or two upon the "jockeying" to which I have already referred.

In the boiler-room the only "jockeying" possible is, in my opinion, that of selecting better coal in one case than in another, and this may be got rid of, and should, I think, be got rid of by prescribing, in the Royal Navy at least, the uniform and invariable use of a given description of coal, which should be the best procurable. It is well known that the heating or steam generating power of different descriptions of coal differs very materially, and it is only from the use of coal of the same kind on all trial trips that similar comparative results can be obtained. Allow me to observe, however, that changes in coal can only influence the development of power, and not the performances of ships. The latter are, of course, proportioned to the power developed, no matter by what means that power is obtained. It is, therefore, for the purposes of comparison between the engines and boilers of different ships, or between those of different makers, that it is desirable to use always the same kind of coal; and for those purposes that condition is almost indispensable. It may occur to some to say that the management of the fires or, in other words, the stoking may greatly modify the quantity of steam and power developed, and this is perfectly true. But the only means of approaching a standard in this respect is, in my opinion, to aim at doing the utmost in every case, by employing the same staff of stokers and others, and that staff of the most efficient kind, on every occasion. And this is what we practically do at Portsmouth and other Government ports in the trials of H. M. ships.

In the engine-room there will always, I fear, be some scope for "jockeying," but I

believe this scope is practically much less than many imagine. In the trials of H. M. ships it is limited by the supervision of several engineer officers, as well as by the general consideration that, upon the whole, it is very doubtful whether frequent interference with the valves does not conduce to priming and to other derangements to such an extent as to make it more advisable, on the whole, to let the engines and boilers do their best continuously throughout the trial. I speak with some hesitation on this point, as there may be experienced "jockeys" present, and as I really am but an amateur observer in this respect; but I can with certainty state that every effort is made in the public service by the officers in charge to make the trials truthful, and on the very last trial I attended the captain of the steam reserve forbade any interference with the engines during the whole period of the trial.

It only remains for me to state why I consider the prolonged trial at sea inferior to the measured mile trial, and you will already have seen that it is on scientific grounds that I give the latter the preference. In the brief and manageable trial at the measured mile you can, when fully prepared, really develope for a given period the full power of the boiler and engine under the most favourable circumstances, and can also observe with exactness the speed obtained by the ship under the impulsion of that power. But send the ship to sea for a day, or even half a day (12 hours), and you at once lose the assurance that you are trying the power of the boilers and engines and the speed of the ship, and find that you are really testing not these, but the endurance of the stokers and engineers. This is the vital part of the question. I appeal to the experience of all present, and ask whether, even in ocean races, it is possible in closely contested races to satisfy the beaten party that the race was lost simply and solely by the inferiority of their steamer. It is not possible, because it is not the real qualities of the steamers that in all cases, or even often, decide such contests. In the most important and interesting ocean race that I ever attended (that between the *Helicon* and *Salamis*) the faster vessel lost much of her credit owing to what I may call the accidents of the stoke-hold. In one vessel (the *Helicon*) we knew that we fell greatly short of our maximum speed, owing to our deficiencies in this respect; in fact, we had to go upon the first grade of expansion, and work easily for fourteen hours out of twenty-seven; and in the other vessel, the defeat which they even then sustained, was boldly attributed to inferior coal. And so, I believe, it would ever be in ocean trials, whether by racing or otherwise. The longer the trial, after a certain length is passed, the less satisfactory will be the result as a means of comparison with other results. You can compare the results obtained on measured mile trials; and although the formulæ which we apply to those results for obtaining the "constants" are but exceedingly imperfect standards of excellence, that does not detract from the validity of the results themselves, which are, in my opinion, far more valuable than any that

could be obtained by prolonged sea trials, when viewed as data for scientific and practical comparisons between ships and engines.

In conclusion, let me beg that you will not consider that my object in this Paper is to oppose the resort to prolonged trials at sea for other purposes. For ascertaining the consumption of fuel, for finding out the most economical steaming speed, for comparing the load and light performances of vessels, and for many other important purposes which it would be easy to name—the ocean trial is invaluable, indispensable. All I desire to maintain is that the measured mile trial is also a very valuable one for other and equally important purposes, and that it is an error, and a very serious one, to suppose that the trial at the mile could with advantage be dispensed with.

DISCUSSION.

Mr. GALLOWAY: The remarks which have been made in the Paper which has been read do not apply to me, as I am neither a shipowner nor an engineer, but I should like to know whether "jockeying," so called, has not been resorted to in other quarters besides amongst shipbuilders and engineers for the purpose of giving a false character to a ship. It is a great pity to refer to a case like this, but it gives me the opportunity of asking a question. Reference has been made to Her Majesty's Royal Navy. Now, I want to ask the Chief Constructor of the Navy a plain question, and I think I have a perfect right to do so. Did the Chief Constructor of the Navy have access to plans which were supplied to the Admiralty before the construction of the *Bellerophon*, and if so, did he adopt the whole or any part of those plans previously supplied to the Admiralty in the construction of the *Bellerophon?*

Mr. E. J. REED: I have no hesitation in answering that question. I had access to innumerable plans, but I never availed myself of them. I had too much to do. I never saw Mr. Galloway's.

Mr. GALLOWAY: Well, then, I must make a statement. Here is the point, I challenge Mr. Reed, though he be styled the Chief Constructor of Her Majesty's Navy, to the proof as to the veracity of the fact, and I will undertake to prove, before any enlightened audience of scientific men, that he has appropriated a portion of plans which were supplied before he took his present office, in the construction of the *Bellerophon.*

The CHAIRMAN: This is not the place for an observation of that kind.

Mr. GALLOWAY: I should not have said so but for the attempt which he has made to throw disgrace upon the constructors of vessels in the merchant service.

Mr. MICHAEL SCOTT: Mr. Reed has spoken upon the great value of the measured mile trial; would not a trial of 10 miles, or something like that, meet the case—not an ocean trial for several days, which involves all the disadvantages he has just referred to in respect to stoking, and so forth. Would not a longer trial than 1 mile—say 10 or 15 miles, be more satisfactory?

Mr. Reed: I think it would, but it is very difficult to get the marks over a long distance, and I know that in the case of the *Mersey*, and other long ships, it has been a difficult thing to get the trial through in a day, and to disembarrass it from the tides by making the cross runs, and you must always do that. You can never run in one direction only. You can scarcely get all the trials through in a single day, owing to the time taken in turning the vessel, and so on. At Plymouth it is exceedingly difficult to get long ships tried at all, even on the 1 mile. I have no doubt that if you could get a course measured for 5 miles, or 10 miles, and disembarrass it of all the circumstances of tide, fog, &c., it would be a much better trial than the single mile; but I am afraid it is not practicable.

Mr. Scott Russell: I will venture to answer the question. For many years I was familiar with a racing distance, and a trial distance of $15\frac{3}{4}$ miles, and which I have no doubt the gentleman who spoke is very well acquainted with. If he is well acquainted with that course, I will appeal to him whether we did not there know a trick or two about "jockeying" quite as good as anything we have heard to-night. I think I could even teach Mr. Reed a dodge or two which he does not know yet.

Mr. Reed: I shall be very happy to learn.

The Chairman: Some observations have been made respecting certain trials, and I think there was a sort of *ricochet* shot intended to touch myself. However, I am very glad to see that there is one person in the room who will understand thoroughly what I am about to say. On very many occasions the trials of certain vessels in the Thames were entrusted to me, and on each of those occasions the observations were taken by myself, independent of every other person on board, and there are several persons here present who know that on every one of those occasions I cut down the figures to decimal parts of a second. I am accustomed to astronomical observations, and to take time to the decimal parts of a second. On every one of those occasions I placed myself in a certain part of the vessel, and I never moved from that position during the whole of the trial, and therefore the distances that were taken were taken as accurately as they could have been taken anywhere upon the ship on the measured mile at Stokes Bay. The distance from the shore, both going and coming, was so small, and the marks were so close, that none of the differences to which Mr. Reed has alluded could possibly have occurred. Very often in some of these experiments there have been certain individuals who have been taking time on their own account, and when we come to consider the length of the vessel, one man taking the time upon the bow, and his friend taking it upon the stern, and comparing the two together, why it is very probable that just that 210 feet would occur, being nearly the length of the vessel. But the trial to which I wish particularly to allude is the *Atalanta's* trial. There was no "jockeying," no nonsense at all about that. The fastest river paddle-steamer was alongside of us. We passed her, crossed her bows, dropped alongside, passed her stern, went ahead of her again, and went past the buoys on the Maplin Sands. I believe that every person, certainly every naval officer on board that ship, was quite satisfied that the velocity, as given in the papers the next day, cut down to the lowest possible figure, was correct. After that, I understand from Mr. Dudgeon, that he left Gravesend, went down the river, was for four hours delayed by fog off Portland, and arrived after all—Mr. Dudgeon will correct me if I am wrong—and was fast in Falmouth Harbour in 22 hours.

Mr. Dudgeon: It was $21\frac{1}{2}$ hours.

The Chairman: I am merely talking of that being a fair guage of what that vessel could do. But

beyond that, she lay to off Dover; she coaxed out one of the mail steamers, ran across the Channel, and beat, I think, by about 30 minutes between Dover and Calais.

Mr. DUDGEON: A little more than 30 minutes.

The CHAIRMAN: These were the best proofs. There was no measured mile, no nonsense. There was half a gale of wind blowing; the Dover packet was almost under water, but the *Atalanta* was as dry as a bone. As to any trials that are carried on in the River during the time that the tide is running, I am inclined to place very little value upon them, because certainly the pilot is rather interested in the trial of the vessel, and he will edge her in shore with an adverse tide, and a little off shore for the other tide. I think, however, that the Paper which Mr. Reed has been kind enough to give us is one of very great importance, and very great value, and I am sure you will all agree with me in giving him our hearty thanks.

Mr. REED: I only wish to say, Mr. Chairman, that the manner in which you have received the remarks I made during the reading of my Paper, is not what I contemplated; I merely meant that in the course of your long and zealous, and active experience as connected with steamers, you no doubt had on some occasions seen cases of exaggeration. That you yourself should be guilty of exaggeration under any circumstances, or on any subject, is a thing which we all know to be impossible. I wish to be particular in disembarrassing the Paper I have had the honour of reading from any suspicion of its having any direction whatever towards the trials with which the Chairman has been connected.

The CHAIRMAN: I did not say that.

Mr. REED: Or to the trials which you have in your mind. But I do not mind admitting this, that there are passages in the Paper which have reference to the vessels of certain friends, distinguished friends of mine, friends who take every possible opportunity of doing me a good turn, and I can only say that if ever the time should come when I should think it proper or desirable to produce the figures, I think they would be rather awkward figures for those gentlemen to deal with. But I think it is my duty in my present position, to be very forbearing and very kind to those persons who (owing to the evil that exists in all of us naturally) slide into little exaggerations of facts occasionally, and therefore I keep the figures back. But some day I can shew, if necessary, that very important trials, of steamers built and engined by gentlemen who do not hesitate to assume to themselves airs of superiority and airs of fidelity which are not, perhaps, as thoroughly deserved as they might be, have been marked with irregularities in that way. Nevertheless, I hope the time may never arrive when I shall have to put a finer point upon these observations.

ON THE IMPACT OF WATER AGAINST A SHIP, AND ON ITS DIRECTION AND PRESSURE.*

By W. E. Seccombe, Esq.

[Read at the Eighth Session of the Institution of Naval Architects, April 11th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

At the last Session of this Institution, held in the month of March, 1866, a very interesting Paper was read by Mr. Reed, Chief Constructor of the Navy, "On some "recent cases of Apparent Negative Slip in Screw Propellers," which Paper may now be found in the *Transactions* of the Institution for the past year.

Several instances were then given of the trials of various steam-vessels with different forms of body and pitch of screw propellers, in which it was shewn that they apparently went faster through the water than the rate of advance of the screw.

There were various opinions put forward by the gentlemen then present to account for this; but one point appeared to predominate with the majority, *viz.*, that a larger momentum was resident in the "following current" than has been supposed, and that neither its amount nor its effects were yet fully understood; and all were of opinion that it was highly desirable some further experiments should be made, in order to furnish better data for enabling correct conclusions to be drawn on this very important subject. With a view to obtain further information on two important points, *viz.*, the direction the water takes close to the skin of the ship, as she passes through the fluid, and, if possible, what is the approximate pressure of the water on the various portions of the ship, I would submit that the following experiments might be made with advantage.

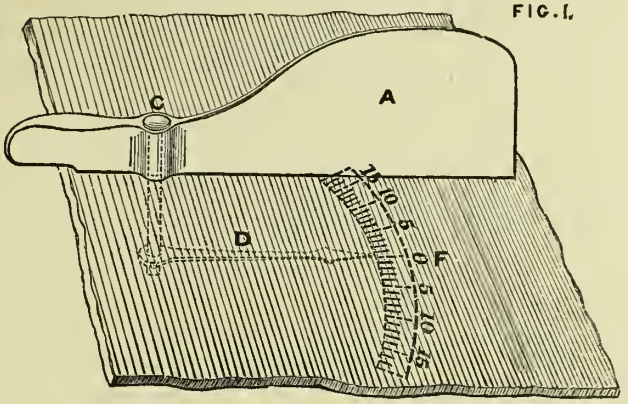
Here I would observe that the means by which it is proposed to show the *direction* of the current of water as it passes the skin of the ship (*see* Fig. 1) is by means of a water-vane, which is constructed as follows:—

The vane, A, which may be made of wood, tin, or zinc, works round a spindle, C.

* Received April 8th, 1867.

This spindle passes through the bottom of a steam-launch, or whatever other vessel it may be intended to experiment upon. As the vane must work freely on the spindle, it is necessary that the fore part or head of it should be thickened, so as to counterbalance the weight of the tail, and let it lie fair on its bearings.

FIG. I.



In order to ascertain and record with certainty the direction of the vane, which will always be that of the water along the bottom of the vessel, the inner end of the spindle C has a tell-tale, D, attached to it, similar to the hand of a clock, which stands in the direct line of the vane, and indicates on the graduations, F, whatever direction the vane assumes.

By these means it is presumed that it will be comparatively easy, under ordinary circumstances, with any required number of vanes attached to the bottom, for persons watching the movements of the hands to register their positions (under any required conditions of increase or diminution of speed of the vessel, &c.) at whatever points it may be deemed necessary to fix the vanes.

At the Discussion which ensued on the reading of Mr. Reed's Paper, before referred to, Mr. Murray, chief engineer of Portsmouth Yard, remarked, that on the trial of a vessel, some years ago, at Spithead, he observed a piece of spun yarn which hung at the sternpost, about 18 inches below the water, to be carried forward with considerable force in the direction of the ship by the current which followed her. A like result was also observed by myself and others on more than one occasion while attending the "trial "trips" of some of Her Majesty's ships at the Maplin Sands during the years 1859 and 1860, when Captain Halsted (now Admiral Halsted) was in command of the steam reserve at Chatham and Sheerness.

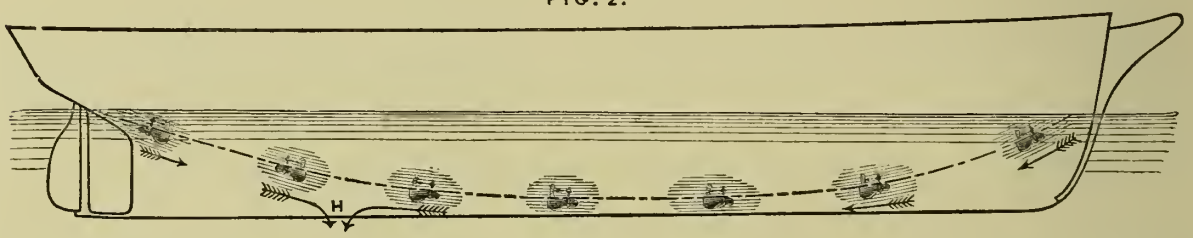
This would go to shew that the ship is followed by a column of water, which to some extent would accelerate her speed by impinging on the after part of the vessel.

Now, supposing this to be the case, what would be the result with regard to the current of water along the vessel's bottom? That all along the fore part of the ship, and beyond the midship section, the water would pass along the bottom nearly at the uniform rate of the ship's speed (of course leaving out the friction of that part of the water in direct contact with the bottom, and to some extent carried along with it); but after the water leaves the midship section, as it passes along the run and nears a certain

point towards the stern of the ship, the speed of the water would seem to be diminished until it comes to a standstill at the point where the current from forward and the after current (which travels, as stated, faster than the ship) meet. The same difference of speed would be manifested in the after current, but in the opposite direction, the speed, in this case, being greatest at the after part.

Now, I would beg to submit that the direction of the current of water, under any circumstances of speed, would be clearly pointed out by the water-vanes, if they were placed at convenient distances along the bottom of the vessel, after the manner of Fig. 2;

FIG. 2.



and it would then be seen, keeping in mind the supposition that the "after current" is flowing along with greater velocity than the ship, that the foremost vanes would be pointing aft, and the after one or two pointing forward; and at a certain point the two currents of water would meet, which, for the sake of illustration, has been assumed to be at H.

It is very probable, in this case, that the point will vary with the rate of speed at which the vessel goes through the water; but, with the vanes placed not very far from each other, this could be ascertained with comparative accuracy under the various circumstances before mentioned.

But, supposing the theory of the rapid after current to be wrong (as some persons strongly maintain), and the point is conceded that the ship actually does outstrip in point of speed the current which follows her, in this case it is presumed that the "vanes" would clearly demonstrate this fact, inasmuch as they would, without exception, all tend from the bow and lie in the direction of the water along the bottom of the ship—in fact the vanes, being so nicely balanced, cannot but take the direction of the current, whatever may be the circumstances which arise to alter its course. It is therefore considered that they would, when placed near to where it was deemed desirable to fix the bilge-pieces, give the direction of the current of water along the bottom of the ship so as to shew the position, longitudinally, in which the bilge-pieces should be placed, so as to offer the least resistance in passing through the fluid; and any model of a vessel so operated on would clearly shew where to fix the bilge-pieces, and general conclusions

might thus be drawn, from actual experiment on particular vessels, to suit others similarly constructed.

We have hitherto only dealt with the *direction* of the current of water in passing along the bottom of the ship; and while it is with some small degree of confidence in its success that I would submit the plan of the "water-vane" to secure that object, it is with a different feeling that the arrangement for attempting to obtain the approximate pressure of the water is introduced; but as one of the principal objects of this Institution is to investigate whatever may be advanced which has any *show* of truth in it, I will content myself with simply stating the proposed plan of operation, and, in the absence of any experiments on the subject, leave it with the gentlemen present to draw their own conclusions on the practicability of the method, which is as follows:—

Let there be inserted in the bow of the vessel metal tubes of uniform size standing parallel to the middle line of the ship, and with their upper ends falling aft at a certain angle from the water-line, so that the water entering the tube at the lower end would be forced up by the velocity of the vessel, the resistance being shown by the height of the column of water, glass tubes being inserted at the upper end at the height of the water-line, so as to shew the rise and fall of the water; or, otherwise, ball-floats might be used, with a gauge, at the upper end of the tube, for this purpose.

Tubes thus placed on the bow, at various angles, from the square or right angle to the fore-and-aft line, would, it is thought, receive the water into their lower ends, and shew a certain rise in the column of water in proportion to the angles at which they stood.

Now, for the sake of simplifying the experiment, it would perhaps be better to consider the bow of a vessel which stands vertical, so as only to have one angle to contend with, *viz.*, that caused by the curve of the water-line and the fore-and-aft stand of the tube; and, what would perhaps be still better, is to mock out the bow of the launch to be experimented on something similar to the form of a copper punt, as shown on Fig. 3, when several tubes could be placed side by side in each space, all at the same angle fore and aft, so that by observing them at one and the same time they may be a check to each other; for, if there be any truth in the theory, the water in each set of tubes (say three or four in a set) will stand at the same height, and rise and fall together, as the speed of the vessel may vary.

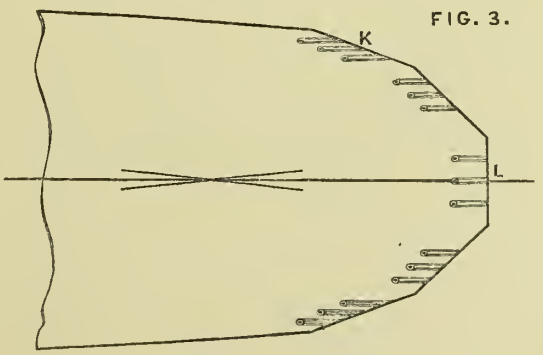


FIG. 3.

Now, it would *appear* that at that part of the vessel which is not far from a fore-and-aft line, *viz.*, at K, the mouth of the tubes would be less inclined to the current than in the next space further forward, and therefore the tendency of the water to rise in the tubes would be less in proportion. The same remarks would apply to the other spaces, as the angles differed; and on coming to the tubes inserted at L, it ought to be found that the column of water was highest in them, because the mouths of the tubes are opened direct so as to receive all the force of the current coming against them.

I would therefore submit that if, on experiment, it was found that the columns of water in the after set of tubes were (at different rates of speed) of uniform height, but standing lower than the set of tubes next before them, and so on until arriving at the foremost set, which was found to register the highest uniform column, a fair inference might be drawn from the height of the column of water as to the resistance of the fluid against the bows of a ship where the angle would compare with the angles before experimented on.

With regard to the after part of the ship, it is presumed that if tubes were placed, say, in a vessel with a full after-body, having the mouths of the tubes at right angles to the middle line—if the theory be correct that the *after current* of a screw-propelled ship flows faster than the vessel—the water would then be forced up the tubes in proportion as the speed of the ship was increased; while, supposing the correctness of the theory that the ship goes faster than the current which follows her, in this case increase of speed would appear to cause less pressure of the fluid on the after part; and in this case the column of water in the tube would proportionably *fall* with the increase of speed of the ship; and thus at the after part of the vessel the tubes would appear to act in conjunction with the "water-vane" in determining whether the after current went faster than the vessel or otherwise.

It is of course assumed that these experiments are to be tried in perfectly calm weather, so as to be free from wave, as any amount of unsteadiness in the vessel would interfere with the steadiness at which the column of water was held in the tubes: also those persons who are on board the craft must be seated so as to maintain a constant water-line, or otherwise it would entirely stultify the operation.

In conclusion, I would beg to remark that if the experiments before described shew the results anticipated, there would not be any difficulty on the part of the mathematician, who so well understands the common law in hydrostatics, *viz.*, that the column of water increases in pressure in proportion to its height, to deduce from these data some valuable information on the law of the resistance of fluids.

But I would not lose sight of the fact that the principle is as yet untried, and would therefore submit it to the better judgment of the gentlemen present whether they think it worth the trouble of practically testing its results.

DISCUSSION.

Mr. Cowper: Perhaps I may be allowed to state that I brought forward a similar proposition three years ago at the Institution of Civil Engineers, and I would ask the Members to look at this little model with vanes which I produced at that time. I quite agree with the remark of the writer, that it would be highly important to ascertain in what direction the water goes, and really think this model shews a handy way of getting at it. I also found that the mouth of a tube cannot be placed so as accurately to gauge the pressure against the side of the body, because when you cut away the side of the body to insert the tube, you cut away that which is the very thing you want to measure the resistance of. Therefore, you have not the side of the body to deal with, but you have an open-mouthed tube. That tube, according to the direction in which it is placed, to the side of the ship, will either throw water out or draw water in; it will either gather water or lose it. I then thought I would cut holes in the side of the ship, and put a number of pistons into them with springs upon the inside, to see what the resistance would be. That, of course, would be a very expensive mode, but the idea soon occurred to me of putting a mackintosh skin outside the vessel, and putting springs against that, to get at the pressure. Then this idea of a mackintosh skin outside the ship suggested at once the obtaining an equal pressure inside, by filling it with water. I then made a rough thing like this, (*exhibiting a model*) having calico sides and a wooden bottom, with straight water-lines; there was not the least idea of curves, so as to *coax* the water, it was filled entirely with water. If you then immersed it in the water, forcing it down, so that the water-line was just at the top, and then drew it through the water, it was most beautiful to see how the increased pressure of the water at the bow gave a hollow line at the bow, and how it filled out and made a round line here (*pointing to the model*). The stern I cannot say so much about. I have tried it both ways. I intended to ascertain whether the water would rise up from below and form a wave, or whether it would close in from above, but I have not a satisfactory result from the after-body; though from the fore-body I have. I should like very much indeed for some other gentlemen to carry the investigation a good deal further, for I believe if we followed the lead of the water, we should come to the true curve. I think such an experiment would lead to good and important results; at all events, it would teach us something as to the way in which the *water would like to go.*

Mr. Rigg: As the mode which has been described in this Paper for ascertaining the direction of the water currents is exactly the same that we employed in observations on the screw-propeller, I may be allowed to say a few words on the subject. We made use of one vane similar to those shewn on Mr. Seccombe's diagram. By it we ascertained the direction of the water, and afterwards held the vane at right angles to the current by means of a spring-balance. This plan gave the weight in pounds on the area of the vane, no tubes were required, and the same apparatus indicated both direction and pressure.

Mr. NAPIER: The tubes, moreover, would only indicate the pressure when the water was at rest. It would not give you the pressure in any motion of the vessel upwards or downwards.

Mr. COWPER: I think the tubes give a very false impression.

Mr. NAPIER: A single tube would not do at all.

ON THE CONSTRUCTION OF THE SIDES OF ARMOUR-PLATED SHIPS.*

By Captain Leopold G. Heath, R.N., C.B., Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

The great strength now required in armoured ships, together with the prestige of wooden backing, have forced our Naval Architects to adopt designs of enormous thickness; the sides of the *Hercules*, for example, being 51 inches thick at the water-line, and 48 inches in the wake of the guns—of this thickness about 3 feet is made up of wood.

The thickness is detrimental:—

1st.—Because it impedes the training and working of guns.

2nd.—Because it diminishes the internal capacity of the ship.

3rd.—Because it increases the leverage of the armour plates upon the ship's side proper, and the strains when the ship rolls are thus much increased, as also the tendency to leak at the bolts.

The wood is detrimental:—

1st.—Because it is liable to deterioration by age and moisture.

2nd.—Because it is liable to destruction by shell firing.

3rd.—Because it forms a yielding, and therefore a bad, outer bearing for the armour bolts.

When, however, the attack was made, as in the Shoeburyness campaign of a few years back, with round-headed shot, the wood was a most valuable adjunct to the defence, because the round-headed shot, when it broke through an armour plate, carried forward with it a large area of the plate, and this acting upon the wood, the remaining energy was taken up by the pliant yielding substance, and was thus spread over a still larger surface. The attack is now conducted by means of very hard sharp-pointed projectiles which do not, when they penetrate, push an area of plate *before them*,

* Received March 12th, 1867.

but which effect an entrance by wedging both plate and backing on one side—and this backing, being only of yielding wood, is almost valueless. (*See* Fig. 1.) These

FIG. 1.*

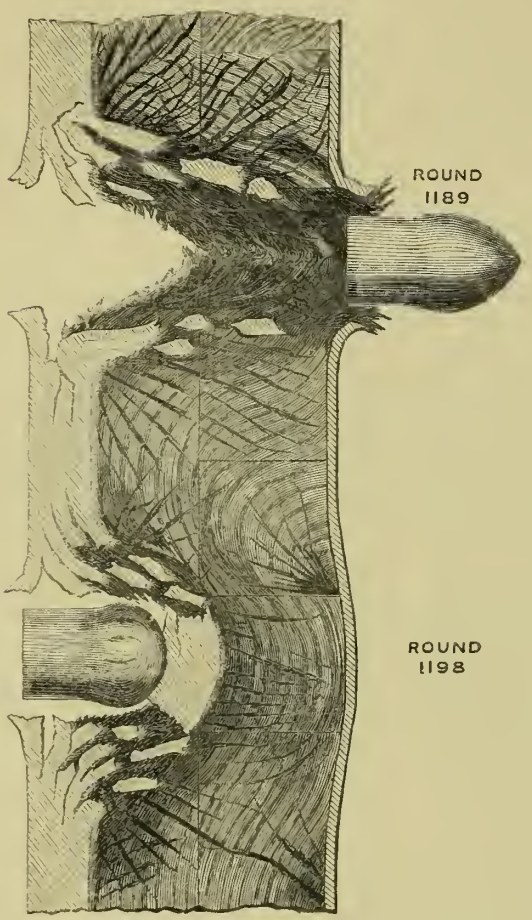
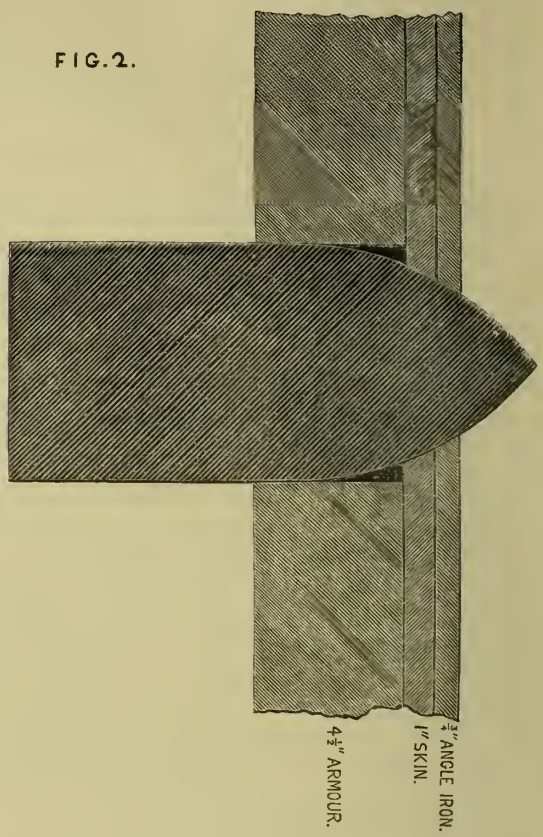


FIG. 2.



considerations clearly shew that the time has come for attempting to get rid of all wood in the sides of our ironclads; and if successful in the attempt, we shall by the same process reduce the enormous thickness of side incidental to the present system.

Purely iron targets were tried by the Iron Plate Committee, by Mr. Scott Russell, Mr. Fairbairn and Mr. Samuda; but in all of them the iron backing substituted for the wood of the *Warrior* was placed in juxtaposition with the skin of the ship, and amounted in fact to a mere thickening of the external armour plate, by the addition of one or (in the case of Mr. Scott Russell's target) of two thinner plates behind it. When I first

* Fig. 1 is meant to show how a round-headed shot carries a piece of armour plate in front of it, whilst a sharp-pointed shot simply pierces. The shot of pointed form, although shown in the wood-cut as emerging whole, is believed to be almost always, if not invariably, broken up.

realized the fact, that, the nature of the attack having changed, it was essential that we should also change the nature of our defence, I was impressed with the notion that it was in this direction that we should turn our attention; but on further consideration it seemed clear, that any such structure, whose backing and skin together were less in thickness than the length of the nose of an attacking shot, might be penetrated by the point, before the whole of the nose had got through the armour plate proper, and therefore before its protective power had been fully exhausted. (*See* Fig. 2.) I observed, moreover, that in almost every case chilled projectiles were broken up by passing through a thick plate, and that the rear face of what is called the box target at Shoeburyness, and which has been much fired at, is merely scratched and dented by the small broken fragments which have struck it. (*See* Figs. 3 and 4.) I propose,

FIG. 3.

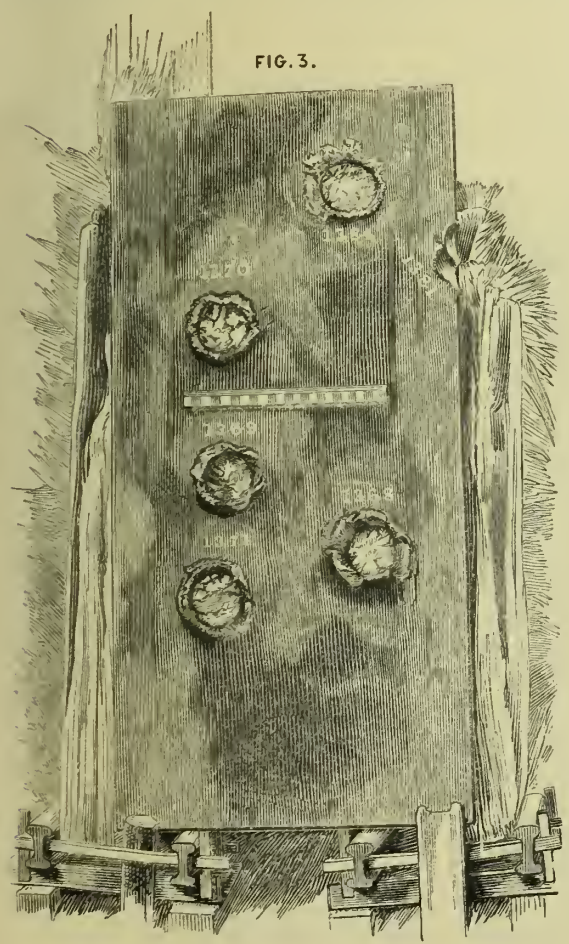
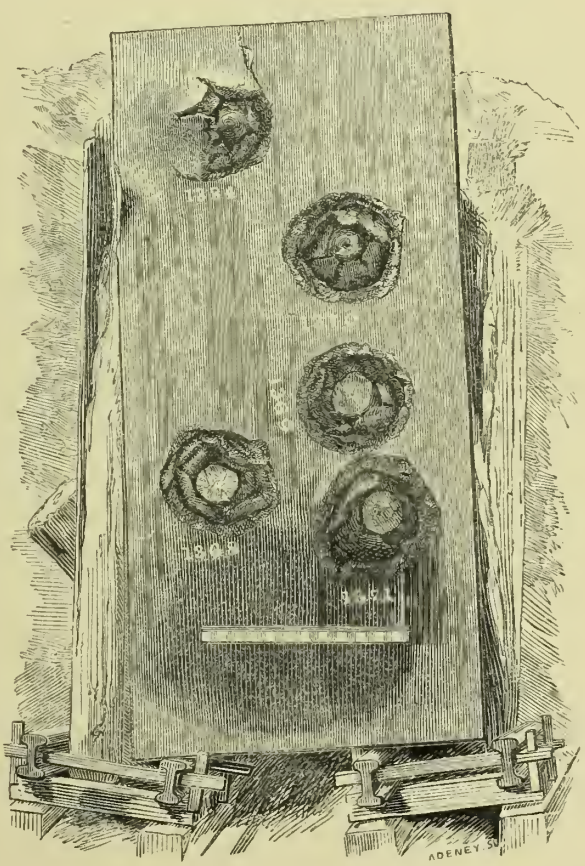


FIG. 4.



therefore, to abolish altogether what is technically called backing, and to push the armour plate off from the ship's side by means of hollow horizontal girders, deep enough

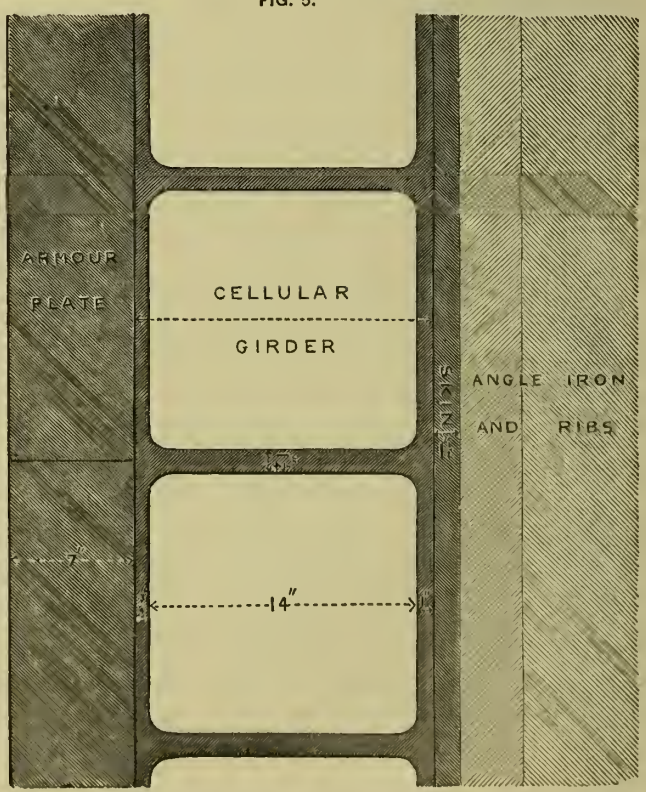
to keep the point of any shot yet made from touching the ship proper, before it has completely penetrated the protecting plate, and I anticipate that the shot will be broken up by the plate, and will merely splash the vital part. As for shells, I anticipate, from the results obtained against the box target by the Iron Plate Committee, and reported by them at page 38, Vol. III, 1862, that they will be equally harmless.

These horizontal girders, besides being shot traps, will enormously strengthen the ship; they should have weeping holes, and a pump should be fitted to the lower one, and man-hole doors might open into them from the ship's side; they might, perhaps, also be made useful in some system of ventilation.

With a 7-inch plate, and a depth of 14 inches for the girders, the total thickness of ship's side would be within 25 inches, which need be but little exceeded for vessels of the very greatest strength. (*See* Fig. 5.)

The structure shown in Fig. 5 would be a little heavier than is the *Lord Warden;* but it would, I think, be stronger and more shot-proof than that vessel when attacked by rifle projectiles; and it is but $24\frac{1}{4}$ inches thick, whilst the *Lord Warden* is 36. It is intended merely to illustrate the system, and I have purposely omitted all bolts and rivets, nor have I indicated how the girders should be built up. This point would require much consideration. They might perhaps be most readily made of H iron, rolled at once to the proper dimensions, the feet being connected by overlapping plates. The armour bolts should be so spaced as to allow a man to crawl through the girders. I have given $\frac{3}{4}$ of an inch as the thickness of the outer surface of the girder, 1 inch that of the inner surface, and $1\frac{1}{4}$ inch that of the horizontal web (supposing the girders to be made of H iron), and I have given the ship a $1\frac{1}{2}$-inch skin; but these are all points for the consideration of a professional Naval Architect. It may be that other dimensions would be more suitable. My wish is

FIG. 5.



merely to lay down the principles,—that the armour plate should be as solid as possible,—that it should be separated from that which it has to protect by an air space in which the shot may break up,—and that the ship's side should be sufficiently strong to resist the impact of the broken pieces.

DISCUSSION.

Mr. ROCHUSSEN: I have arrived at the same conclusion as Captain Heath, although by altogether a different road. I have put upon the wall a suggestion upon which I have experimentally made some progress—certainly not in connection with the Government, but privately. In this diagram on the wall in order to gain a great depth without increasing any weight of iron, I have a 5-inch slab bearing a furrow of 7 inches in height; consequently I have a depth throughout of 12 inches of metal. The projectile we have to take in consideration exceeding 7 inches in diameter, the distance of the furrows at the apex being 7 inches, consequently it follows that every projectile, be it spherical, or flat-headed, or even ogival, must meet one point which is 12 inches from the back; if it strikes this my mode of resistance will be so much more, and if the resistance of armour-plating—as in the case of an ordinary girder—increase in the square of the depth, I then have a depth of 12 inches, equal to $8\frac{1}{2}$ inches of solid armour with a proportion of resistance as 144 to 72. If this principle holds good—and I say I will stake my character so far as to say that the experimental firing which I have carried on myself bears out to a large extent the theory—there is no reason why we should not go farther on, and reach the plan which is on the lower part of the diagram. Here, again, in double furrows, I have everywhere 12 inches of metal, but I have only a weight of $6\frac{3}{4}$ inches, and there my resistance is as 144 to 43 or rather more than $\frac{3}{10}$, without having increased 1 ounce in weight. There is this advantage in that plan as it stands there, that an ogival shot, or indeed any shot not hitting in the axis of rotation, must topple over, and consequently it offers on a small scale that which was planned years ago by Mr. Jones, and if the experiments which are at the present moment being carried on for combining steel with iron armour plate should succeed,—and the experiments certainly look well—and we can have a hard surface cushioned by a layer of soft metal, and then supported by hard steel; this plan would offer by far a step in advance, inasmuch as these ridges or furrows might present case-hardened edges for any shot that might strike it. But I would go farther. The great question at the present moment is how we can cover our iron plate with wood, and then shield it with copper or zinc. The plan I have before me offers a thousand facilities for letting in wood between the furrows. That wood, not forming any essential part of the ship's construction, does not require to have so very strong a fastening as though it were an integral portion of the ship itself. If I am successful in filling these furrows with wood, nothing is easier than to put an inch planking on it. The subject is worthy of long and practical experiments. I just give you the idea of that which appears to promise success.

Mr. SCOTT RUSSELL: We must be very grateful to Captain Heath for having brought us here, in a very condensed form, the result of the great experience which he has had, and the great knowledge which

he possesses upon this subject, and which is probably greater than that of most men; for few men have so thoroughly examined all the cases which have presented themselves in the course of the long series of complicated, extensive, and most valuable experiments which our Government has carried on for so many years at Shoeburyness as Captain Heath has. His opinion, therefore, to me—a shipbuilder, a naval architect—is entitled to the greatest value, not only for that reason, but also for the other reason that he is himself a naval officer of long experience and is held in high respect. I, therefore, must treat this Paper, short though it be, and given in the unpretending manner in which it has been, as one of the most important Papers brought before the Meeting. I am not surprised, first of all, to hear him say that what he has seen at Shoeburyness has removed the whole of his faith in wood-backing. What I have seen at Shoeburyness has also long ago removed what faith I had in wood-backing, and you must give that confession of mine more weight than it is entitled to from mere personal considerations, when I tell you that in the original design which I made for the *Warrior* some years before she was constructed, and afterwards when she came to be constructed—in my two original designs which were approved by the Admiralty, and carried out jointly by myself and the Board in the construction of the *Warrior*—I say I was responsible for the introduction of the wood-backing in the *Warrior*. I did it there upon this principle, that in this world I have had experience enough to know that you ought, if possible, to make only one experiment at a time, otherwise you never know where you are, and as at that time iron armour upon wood-backing had given good results, I said, "Although we are to build an iron ship let us preserve "the wood-backing because we know it will answer; let us not try something of which we are uncertain, so "as to complicate the experiment." Therefore I say, if you like, that I was greatly in error. I say, if you like, that my theory has been entirely refuted by subsequent experience, and I now frankly admit that the experiments at Shoeburyness have destroyed, in my opinion utterly, the value of timber-backing. There I entirely agree with Captain Heath, and I am proud to be able to agree with him, because he has both more knowledge of what has been done in the experiments,—and he has professional knowledge, which I have not. It is, however, a coincidence of which I am proud, that my own observations and experiments at Shoeburyness should have led to conclusions which are not by any means alike in the devices by which he would carry them out, but which are alike in principle, and therefore confirm each other. I must also join with him in the endeavour which we must make to beat Major Palliser, because the battle has been this—first the gun got the advantage of us, then the shot got the advantage of us. Then when the gun would burst, and would go no farther, Major Palliser comes in with his case-hardened shot,—that gun having done its worst, he then proceeds to do his worst with his beautiful shot, and therefore we are now obliged to put ourselves this task—how shall we keep Major Palliser out of our ships? Now, I think the way to keep Major Palliser out of our ships has been very admirably shown to us by Captain Heath. He uses a very insinuating process. Other people went more bluffly to work and with the round-headed shot tried to drive the armour in. Well, it had to do the work too quick, and it could not do it. Moreover, it spread the strain over a large area, and made the large hole which we have seen, but without penetrative power. They then tried a square-headed shot, and that certainly had the advantage that it was able to concentrate its effort in a very small area, and to some extent it succeeded, and to another extent it failed. Then comes Major Palliser, and he says—"I will add to the strength of it by doing it gradually; they know "how to make the armour heavy enough to stop a square-headed shot, but I will so harden, so proportion my "square-headed shot that it shall penetrate one layer of the armour after another, and so I shall get through." Very well. Now, we must keep out Major Palliser's shot; and I will show that Captain Heath's plan to

keep out Major Palliser's shot is, I think, a good one. I join with him in principle, and if I differ from him somewhat in the exact mode of carrying it out, you must take it for granted that it is a difference between a shipbuilder's notion and a sailor's. Now, in the first place, I entirely agree with this plan shown there (*pointing to the diagrams*)—of having a large enough and thick enough plate on the outside to resist and stop the shot, and bring it almost to rest, if not entirely, on its way through the outside skin. I think that is far wiser than doing what some other people have done in some cases—taking away a large quantity of armour from the outside, and putting it on the inside. However, I am entirely of opinion that his policy in putting these large 7-inch plates on the outside is a right policy for stopping that insinuating shot. Then, if the shot passes through, it will pass through with an enormously decreased velocity, and now comes your time to be near the skin to take the remaining speed out of that shot and to protect your ship against penetration. Then I think the mechanical structure of his cells is extremely good. Those cells certainly give additional strength to the ship, as well as resisting power to the armour, and they have the great advantage of subdividing the area which is penetrated, and of having longitudinal strength. Therefore, with all these excellent points in it I entirely agree. I am only going to say that if the actual execution of such an arrangement were to be carried out with anything like a coincidence of my experience and my observation, of what the damage done at Shoeburyness against the targets has been, I should be disposed to carry it out mechanically somewhat differently—but only mechanically somewhat differently. In the first place, I should entirely agree with Captain Heath in keeping that very thick 7-inch plate and armour on the outside.

Captain HEATH: Not necessarily 7 inches.

Mr. SCOTT RUSSELL: Not at all; I mean for this particular shot. I am only dealing with this. I should certainly keep that on the outside. Now as Captain Heath has given us the benefit of his thinking upon this subject, I will just give him the best I can say as to the mode of carrying it out. I have a strong impression that it would be better to confine the armour plates in their place by putting an outer skin even with the ship on the outside of the armour plates, because the extent to which I have seen plates broken up by tumbling off, and then exposing the ship, makes me feel that a large 7-inch plate outside is liable to go to pieces. Therefore, I certainly would enclose that armour plate at each point, not quite as I did it in my target at Shoeburyness, but according to the method which the experience acquired there has suggested, namely, I would make the longitudinals pass through the joints of the plate, and enclose the iron armour bodily within this longitudinal box. I would, therefore, build that part of the ship entirely of longitudinal cells, as Captain Heath does, but I would proportion them to the size of an armour plate, and I would put the armour plate on the inside of this skin, because the armour plate would lie there without any expense of workmanship. A rough, rude block of armour put there would be as good as your expensive, planed, beautifully turned blocks. When it was there I would take care that it remained there, and was supported, because I would line the cellular part behind it. Going farther back, then, than Captain Heath's suggestion—and he has shown the value of that, without doubt—I then come to the inside lining, and I hope Captain Heath will do me the justice to remember that on my target at Shoeburyness—a target which was entirely of iron—I had an iron plate forming an inside lining, and that iron plate was never penetrated.

Captain HEATH: By what shot?

Mr. SCOTT RUSSELL: By an Armstrong steel shot, with 90 lbs. of powder—steel shot—round, not long.

Captain HEATH: I do not pretend to recollect the details of the firing at those targets, but I may say only one shot was fired with 90 lbs. of powder before the *Hercules*, but I do not remember what it was.

Mr. SCOTT RUSSELL: Then I may be in error, and I will not charge your memory with it.

Captain HEATH: I am not sure about it.

Mr. SCOTT RUSSELL: I will take your correction at once. Then I do just as Captain Heath does. I take the inside line. I would have the skin of the ship, I think, quite as wide as he has it, and I doubt if I should put in any wooden lining behind it. I am not certain whether Captain Heath has done it, as one is liable to misunderstand.

Captain HEATH: No wood whatever.

Mr. SCOTT RUSSELL: No wood whatever. Therefore I think, as a shipbuilder, according to the experience I have had, and to the remarks I have made on the target, I would carry out Captain Heath's principle thoroughly. I should only make some differences which I think would largely economise the cost and greatly preserve the side of the ship, because, this being in the inside, the cell which encloses it might be shattered in pieces, but the flexible iron around it would keep those pieces in their place, and so, instead of the ship being peeled, as it is, by the knocking off and tumbling off of pieces of the armour from the bolt fastening outside, those pieces would remain inside and protect the ship.

Mr. GALLOWAY: On these armoured ships will hang some day, probably, the destiny of this great England of ours. Had letters been admissible here, I could with considerable pride have read through copies of letters which I wrote to the Admiralty embodying the principle referred to by Mr. Scott Russell, and that, probably, would give me a little better position than I now feel to have in these meetings of the Institution of Naval Architects. On the whole, however, I see with much pleasure and delight the approach to the application of that which I hold to be a correct principle in the construction of our ships of war. I hold with Mr. Scott Russell that if you encase, as it were, the solid armour plate, and outside of that armour plate have fixed in connection therewith a cellular principle of construction rightly arranged, you will be far more likely to resist the effects of the most powerful shot than by any application of any solid armour that sternly presents itself to the shot. There are very momentous considerations in connection with our ships of war—considerations which I deem to be of the highest national importance and magnitude, and there is one question which I would like plainly, as an Englishman, and on commercial grounds, to have fairly raised and discussed. I should like to ask the question here, and I ask it upon public and national grounds. I ask the opinion of Mr. Reed, the Chief Constructor of the Navy, as to what would be the position of the *Bellerophon*, or any other ship of war a short time after the commencement of an engagement, arising from the concussion of the shot acting upon the frames and acting upon her rivets? I submit, Sir, that her position would in all probability be that she would become a coffin for every soul on board. I submit that this is a subject of vast and vital importance to the Government of this country, and if that Government were to discharge its duty——

The CHAIRMAN: Be good enough to confine your attention to the question before the Meeting.

Mr. GALLOWAY: My feelings have been aroused by what has transpired. I am passing away, as others have done before me, and I want to raise this question. If I have rights, upon public grounds I demand them. If I have not rights, then I must be convinced that I am in error. Therefore, treat me as a man. Give me fair play. I ask no favour. I trust you will hear me.

Mr. E. J. Reed: I will venture to trouble the Meeting with one or two words upon this very important Paper of Captain Heath's, because it certainly is deserving of all the encomiums which Mr. Scott Russell has so well pronounced upon it. I simply want to make a remark or two upon two minor points. The first is that the increase in the weight of armour used in our iron ships, has not led to increased thickness in the side of the ship. I do not know how the question has been with regard to the *Lord Warden*, but there the increase can only be an inch and a half—the thickness of the extra skin. The total thickness is dependant upon the fact of her being a wooden ship. Our iron ships, not even excepting the side of the *Hercules* in wake of the battery, are less in thickness than the *Warrior*.

Captain Heath: Is the thickness of wood in the *Hercules* less than in the *Warrior?*

Mr. Reed: Yes; the *Hercules* target, as I thought was well understood, had an enormous quantity of wood, but the target represented the water-line of the ship; at the battery she is thinner than the *Warrior*. I state that with great confidence. Then another point is in regard to the internal capacity—and I mention it because, though an interesting fact, it is of very secondary importance to me, because the enormous weights which have to be carried in the large iron-clads involve so much buoyancy, and the complements of stores we carry are obliged to be so cut down on account of the weight of the armour carried, that the internal capacity is usually ample for all its purposes; and while I am one of those who believe that every cubic foot of internal capacity is valuable, yet still I wish it to be understood that there is room enough consistently with all the ordinary usages of the service, and that in abundance. There is one other general remark I should like to make about the system of Captain Heath; which is, that I think it will be obvious that unless it was very much more considered than it has been in the form in which it appears here, it would be utterly inapplicable to any other than the straight portions of a ship, because bending 14-inch girders round the curve of a vessel would be out of all consideration I think. At the same time, I do not attach any very great weight to that, because Captain Heath might very well reply that you might make your girders to the shape, and that would meet that difficulty to some extent, although it would involve great complications and difficult workmanship, where the horizontal webs of the girders approach each other round the curved portions. At the same time this principle stands on its merits apart from that consideration, because, as he said with reference to the battery portion of the ship, that could be undoubtedly made upon this plan with ease; and so far as that goes the system is unaffected by this remark—that is to say, unless it were carried out on a somewhat enlarged scale. There would be a difficulty in building it with these dimensions—a very great difficulty. But what I am unable to understand is how any one can imagine that the way to protect an iron plate from the blow of a shot is to put something rigid between the plate and the armour. If one wants to drive a bolt that it is difficult to get at, you take another iron bolt, and drive upon that, with the absolute certainty that the blow you put upon it will be transmitted through it to the bolt which you wish to drive. So, if you wish to protect the skin of a ship by an armour plate, it appears to me the first thing you want to do is to let the armour plate be broken. That is the very object you have in putting it there. You want to preserve the skin, and in order that you may preserve it you want something else to take the momentum out of the shot. Something must take it out, and what you want is that it shall not be the skin of the ship that shall be called upon to do it. Now, if you take an armour plate and the ship's skin, and interpose between the two a rigid object, it will be sure to transfer the force of your blow to the skin of the ship, and cause the very evil which you desire to avoid. And I say that if these horizontal ribs in these cells are strong, a blow striking outside of them on the armour plate opposed to them will infallibly be transmitted very

directly and very effectively to the skin of the ship, and must therefore cause injury. That is not a conclusive argument against the system, because—I do not know however, whether Captain Heath will agree with me or not upon this point—if the system were adopted, you could make these ribs so that they should crush up and be incapable of transmitting the blow to the skin of the ship. Then I am free to admit that you could get the iron plate fractured, could get it crushed up, and get the force taken out of the shot, but not by the skin of the ship, which is the primary object. I must confess, as far as I can see, and as far as I have watched the Shoeburyness experiments, it does appear to me that the wood is very serviceable, and that it is exceedingly difficult to replace that wood by an equal weight of iron in any form in which the iron would be as useful as the wood. I am not, in saying that, at all likely to pass by the very forcible consideration which that diagram illustrates, namely that Major Palliser's shot is a very much more difficult one to deal with, and requires a different resistance to the shots which were in vogue before it. At the same time the principle appears to me to hold, that the interposition of a moderately yielding material between the plate which you wish to fracture, and the plate which you do not wish to be fractured, is a good and a proper thing, and although I believe we shall all be very glad to get rid of a perishable material between two almost imperishable surfaces—although we should all desire to do that—yet I cannot help thinking that the proposals now before the Meeting, whether Mr. Scott Russell or Captain Heath's, would involve a very great outlay indeed, greater than was in the first instance contemplated; and when you come to repairs it seems to me a very intricate question to decide how you can possibly make an effectual repair of a ship constructed upon either of these systems. In the ordinary system when your ship goes into action, and your plate gets injured, you can take it off easily by known means, and put another on. But how in this case you are going to repair the plates which are involved in this system, or in the plan shown by Mr. Scott Russell, I am at a loss to conceive. I only mention these considerations—not at all with the object of throwing any damp upon the admirable suggestions of Captain Heath, but merely as points which we should here consider, and which deserve consideration under the circumstances. With regard to Mr. Rochussen's suggestion, I am not aware whether he remembers that that was a scheme proposed over and over and over again to the Iron Plate Committee. It was one of those four hundred proposals with reference to which the Iron Plate Committee said in their closing report that they had examined them all, and considered them all, and had come to what was to us a very satisfactory conclusion, namely that they were all inferior to a solid plain plate formed in the ordinary manner and attached in the ordinary way.

Mr. Bramwell: It appears to me that there is one mode not yet alluded to in which a cellular system may be advantageously used, and that is by making the armour plate itself cellular, by which I mean that the armour plate should be composed of a front part and of a back part connected the one to the other by ribs, so as to leave cells between these ribs, and that the armour plate thus formed should be welded up into a complete structure. I do not know that such a plate has ever yet been made—and I am well aware that at the outset of the manufacture there would be difficulties to be overcome—but I believe that it is perfectly practicable to make such a plate, and that, in fact, it is a mere question of cost; and that, if enough were paid for it, a cellular armour plate, all welded in the solid, could be produced, say, for example, 1 foot in thickness; but which, owing to its being cellular, should not weigh more than a plate of 8 inches thick; and that thus much extra strength could be obtained without the extra weight, which forms the great difficulty that has, according to the present system, to be met when thicker armour plates are used.

The CHAIRMAN: I believe that same principle was advocated by the late Mr. Roberts; he perforated the plates.

Mr. BRAMWELL: I am glad to find I am following so able a man.

Mr. GALLOWAY: It is precisely what I recommend.

Captain HEATH: I think the position which Mr. Rochussen has taken up has been fully answered by Mr. Reed. The ridge and furrow principle has, I believe, been very fully tried, and the results are very fully recorded, and I have no doubt that upon application to Dr. Percy, or any member of the Iron Plate Committee, Mr. Rochussen would get access to their official reports. I think the general result of all these sorts of "fancy plates," as I may call them, is that their average strength is about the same as their average thickness. I am very glad to find that I am supported in my general views by so very high an authority as Mr. Scott Russell. He sets me up as a very high authority, and makes it somewhat difficult for me to avoid blushing when I hear him speak. I might say the same of him, no doubt, and therefore I claim his alliance as a very valuable one. There is one point, however, which I think he has rather overlooked. He says it is essential in any proper system of defence that the defence should very much reduce the velocity, and therefore the energy of the shot before the shot strikes on the ship's side, and he seems to attribute the value of the armour plating as I propose to place it, entirely to fulfilling that function. But he omitted to state that in every recent case—in every case that I have observed—at Shoeburyness, the velocity of the shot is not only decreased, as it would be, of course, but the shot itself is broken up into "smithereens," that is the only expression I can use. In all cases it has broken up into very small pieces indeed. There are cases, I think, where half the shot has gone on, or a portion of the front part of the shot. So that, if the energy of the whole shot is reduced in any proportion, the energy of one quarter of the shot, supposing the shot to be broken in only four pieces, is one fourth of the reduced energy, and each piece striking the skin of the ship, which is what you want to protect, has really no effect whatever. If Mr. Reed, the next time he goes down to Shoeburyness, will give his attention to the back of the box target he will find it is literally nearly smashed. There is one place where Major Palliser's shot has indented 2½ inches deep. There is nothing but scratches all over the plate. Then I think that Mr. Scott Russell has also rather overlooked the very great diminution in the buckling of plates since the advice of the Iron Plate Committee was taken, and the plates were made much larger. The buckling of plates is now hardly to be thought of. All the large plates, especially the 8-inch plates, are hardly buckled. The ship would be destroyed by perforation, and not by peeling off, as you have described. I am very anxious not to put myself forward as a shipbuilder, and not to put this forward as a shipbuilder's question. No doubt Mr. Scott Russell's plan of boxing in the plate would be open to the objection pointed out by Mr. Reed, namely, the difficulty of repairing. But I merely lay down the principle. The way and the means to do it I do not pretend to state. As to the horizontal pieces of the girders being too rigid, I may just say, that in the original drawing I sent to the Admiralty the girders were built up separately, with different plates riveted together round and round, and that, I suppose, would meet your view of having some yielding material behind the plate. The T iron, you think, may be too rigid?

Mr. REED: Yes.

Captain HEATH: Then, with respect to the thickness of the *Hercules* target, I can only say that I

am very sorry to have misrepresented the thickness of the *Hercules*, but I took my figures from the official description of the target sent down to us. Half of it had an 8-inch plate, and half of it a 9-inch plate. I understood the 8 inches to represent the ship in the battery, and the 9 inches in the water-line. Then, as to the difficulty of building, or rather of bending the girders to the ship's side, Mr. Scott Russell has answered that. You would probably, I suppose, build the girders on the ship's side bit by bit. Then, as to the repairs, that, again, is a shipbuilder's question, but I can really see no more difficulty in repairing a ship of that description than in repairing a wooden ship. In the one case you take off a damaged plate. Well, that is as easily done in one case as in the other, for your girders are built up of separate plates riveted together. You take off the damaged plate, and you replace it just as you replace a plate in the bottom of an iron ship. I think that is an objection which is hardly a valid one, and I think I have now answered all the objections made.

The CHAIRMAN: I am sure we are all much obliged to Captain Heath for his valuable Paper. As I am now obliged to leave the Meeting for a short time, perhaps Mr. Reed will take the chair.

ON ARMOUR FASTENINGS.*

By Major Palliser.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; E. J. Reed, Esq., Vice-President, in the Chair.]

During the course of a Paper which I lately read at the United Service Institution, I performed a small experiment for the purpose of illustrating the necessity of uniformity of longitudinal strength in a cannon, and I have since been invited by some gentlemen to repeat that experiment, and also to say a few words about armour fastenings, in your presence.

I think that out of the many proposals for the attachment of armour plates, there are only three methods which deserve special notice here.

1.—The plan of continuous riveting proposed by Mr. Scott Russell.

2.—The French or wood-screw bolt.

3.—The through bolt.

The first system consists in attaching the plates by means of longitudinal stringers or ribs which pass through the joints of the plates, and are then riveted over the entire length of the joints. Some of these continuous rivets were countersunk, and others in relief upon the plates. Each kind was severely tested at Shoeburyness about five years ago, and answered admirably. The plates were held perfectly flat upon the backing, and none of the rivetings were broken. I think the system might be applied with much advantage in the construction of iron shields for the embrasures in permanent fortifications. With regard to its applicability to the building of ships, I do not venture to give an opinion—not being a naval architect—in the presence of so many gentlemen of that profession.

The second or French bolt I have termed a wood-bolt, since it only fastens the

* Received April 19th, 1867.

plate to the wood-work. A large coarse thread runs spirally along the whole length of its tapered shank. These bolts do not break, only because they draw out of the wood, and thus the plates quickly become half detached, as was seen in the trial of the *Flandres* target at Shoeburyness, August 4, 1864, the plates of which target were secured with these bolts. Moreover, armour plates attached on this system become so much top hamper, tending to strain the ship, and open her joints in rough weather.

The third system, namely, that of through bolts, possesses this great advantage, that, provided the bolts do not break, they bind the armour, the wood backing, the inner skin and ribs into one compact mass, and thereby strengthen the whole structure. The strain, however, on through bolts, caused by shot penetrating the armour plate, and pressing the backing against the inner skin, is so great and sudden that ordinary through bolts invariably break in the screw threads. I propose to illustrate practically the necessity of a stretching quality in a bolt which is required to resist a sudden or dynamical strain, and shall do so by allowing a weight to fall freely down a bar, suspended vertically until checked by a nut at the lower end. I also propose to prove theoretically, 1st, if the bolt be capable of stretching through a distance equal to the height through which the weight falls, and, if its resistance while stretching be uniform, that its resistance need only be sufficient to support the weight itself when gradually applied; 2nd, if the bolt be not capable of stretching at all, that its strength must be infinitely great as compared with the pressure suddenly applied to it, to enable it to support that pressure.

In order to prove the theoretical propositions I shall read an extract from a letter which I addressed to the Secretary to the Admiralty on the 13th of December, 1862, and which is printed in the report of the Iron Plate Committee :—"Having some six months "ago been present at the trial between the 150-pounder smooth-bore gun and the *Warrior** "target, I noticed two facts, 1st, that the screwed breech blew out, carrying with it a "portion of the gun, which broke off in a plane perpendicular to the axis, and passing "through the last complete turn of the thread of the screw; 2nd, that on the iron "plate being struck by the shot, the nuts fell off the bolts by which the plate was "attached to the wooden backing, owing to the bolts breaking off in the last complete "turn of the thread of the screw.

"I conjectured at the time that each of these results was due to the same cause, and "was induced to make the accompanying experiments with a view to verifying this "conjecture."

* The experiment referred to was against the *Minotaur* target—not the *Warrior*—and took place July 7, 1862.—W. P.

Extracts from Private Experiments made on the Strength of Screw-bolts subjected to impulsive Strains.

"Dublin, November 27, 1862.—The power was applied by means of a weight of "97 pounds, which had a hole bored through it, passing through the centre of gravity. "The bolts were severally attached to a rigid iron cross beam at their upper ends, and "hung vertically downwards. The weight was threaded on each bolt, on the lower end of "which a screw nut (larger than the hole through the weight) was subsequently screwed. "The weight was lifted up the bolt until it touched the cross beam, and then allowed to "fall freely down the bolt till checked by the nut at the lower end.

"November 28, 1862.—No. 11.—Thickness of bolts $\frac{1}{4}$ inch increased in thickness "at the screwed part, and screwed with $\frac{5}{16}$-inch screw tap. First fall 11 inches, did "not break; stretched $\frac{1}{4}$ inch. This bolt sustained seven full falls of the 97-lb. weight, "and broke in the shank at the eighth; it stretched in all 2 inches. The falls of the "weight thus varied in height from 11 inches to 13 inches.

"No. 12.—Bolt $\frac{3}{8}$ inch in diameter, screwed with $\frac{5}{16}$-inch tap. Fall of weight, "6 inches. Broke first fall *in last* turn of screw thread.

"No. 13.—Same as last. Fall of weight, 5 inches. Broke first fall *in last* thread "of screw.

"December 1.—No. 23.—Bolt similar to No. 11; $\frac{1}{4}$ inch thick. First fall not "measured, probably $14\frac{1}{2}$ inches; permanent stretch not taken. Second fall, 15 inches; "stretched 1 inch. Third fall, 16 inches; stretched $\frac{1}{4}$ inch. Fourth fall, $16\frac{1}{4}$ inches; "stretched $\frac{1}{2}$ inch. Fifth fall, $16\frac{3}{4}$ inches; stretched $\frac{1}{2}$ inch. Sixth fall, $17\frac{1}{4}$ inches; "stretched $\frac{1}{2}$ inch. Seventh fall, $17\frac{3}{4}$ inches; bolt broke in shank."

Nos. 11 and 23, both bolts of an uniform thickness of $\frac{1}{4}$ inch, thus sustained, without breaking, respectively seven and six blows of the 97-lb. weight, falling on an average, in the first case, 12 inches, and in the second, about 15 inches; while the two $\frac{3}{8}$-inch bolts, each reduced at one point to $\frac{5}{16}$ inch, broke; the first under the first blow of the weight falling through only 6 inches, and the second under the first fall of only 5 inches. On the other hand, the two last-named bolts would be stronger when subjected to a statical strain than the first two in the proportion of 25 to 16, and yet when the strain becomes impulsive the latter prove to possess upwards of ten times the endurance of the former.

"The work accumulated in the weight is $\frac{Wv^2}{2g}$, where W equals the weight, v, the "velocity at which it is moving at the instant it strikes the nut, and g, the acceleration "due to gravity.

" If the bolt does not break under the shock, it must perform an amount of work " equal to that accumulated in the weight. Its capacity for performing this work " depends upon its extensibility in conjunction with its cohesive strength.

" Thus, if S denotes the distance through which it stretches, and R the mean of " the variable resistances it offers while stretching, then R S will denote the work it " performs, or $R S = \frac{W v^2}{2g}$.

" It will be evident from this equation that the smaller S becomes, the greater " must R be.

" If H be the height due to the velocity, v, then since $v^2 = 2g H$,

$$\frac{W v^2}{2g} = W H = R S.$$

" Thus, if the bolt were composed of some very extensible substance, such as " india rubber, which would stretch through S = H, then need R, or the mean of the " variable resistances it offers while stretching, only equal a constant force which would " produce an acceleration in the weight equal to g, or R need only equal W."

Thus, if the resistance of the bolt while stretching be uniform, that resistance need only be sufficient to support the weight when gradually applied to the bolt. *Q.E.D.*

" If on the other hand, the bolt were composed of some unyielding substance " made still less extensible by causing any extension to be confined to a point, which " might be done by cutting a deep sharp knife-edged groove round the bolt, then " must R be infinitely great, since S had been made infinitely small; for $R = \frac{W}{2g} \frac{v^2}{S}$, where " S is an infinitely small fraction."

Thus, if a bolt cannot stretch at all, its strength or resistance must be infinitely great, as compared with the tensile strain suddenly applied to it, to enable it to support that strain. *Q.E.D.*

I shall now practically illustrate the necessity of the stretching quality in a bolt required to resist a sudden strain, and, I hope, verify the previous experiments which I have quoted.

A stout iron bar is suspended from the apex of this tripod. It has a hole $\frac{9}{16}$ inch in diameter, bored about $\frac{3}{4}$ inch deep up its lower end. This hole has a female screw-thread in it, which receives the larger screw-thread on these bolts, which are 3 inches in length. All these bolts are screwed at the other end to $\frac{3}{8}$ inch, and screw into this large nut. Some of the bolts are reduced for a length of 2 inches to $\frac{9}{32}$ of an inch. The others are of the ordinary pattern.

This piece of iron or hammer, which is threaded on the bar, weighs 28 pounds, and the length of the fall is 2 feet.

[Major Palliser first attached an ordinary bolt to the lower end of the bar, and it was broken by the first fall of the weight. A second ordinary bolt was tried, and it broke at the second fall.

A bolt with the reduced shank was then tried, and it withstood nine falls of the weight, being gradually drawn out by each blow. At length a weak place became defined, and the bolt broke in its shank at the tenth fall of the weight. The original length of the reduced part was drawn out about 30 per cent.]

I shall conclude by giving an account of some of the trials to which these bolts (which I propose to call "stretching bolts") have been subjected at Shoeburyness.

The first occasion upon which the stretching bolts were tried in public was on December 22nd, 1863, when a 4-inch plate, attached to a block of granite, 3 feet thick, by 1½-inch bolts, was fired at with a 68-pounder without any injury being done to the bolts. These bolts were made by the Millwall Company.

The next occasion was on the 16th December, 1864, when 1½-inch stretching bolts were employed in a portion of a target representing H.M.S. *Warrior*.

Extract from Report of Ordnance Select Committee of the Trial of Warrior Target, on the 16th December, 1864.

The shot used in this experiment were of three kinds, *viz.*, Firth's steel, steel manufactured at the Atlas Works, Sheffield, and Major Palliser's chilled cast-iron shot. The weights of the shot were 100 pounds, and the charges used were 25 pounds and 17 pounds, fired from 7-inch muzzle-loading shunt rifled gun of 134 hundred-weight.

"The fastenings of this target suffered very severely. During the fifteen rounds "which were fired in this experiment, eighteen armour-plate bolts, thirty backing bolts, "and eighteen rivets were broken. Only three of Major Palliser's bolts were broken, "notwithstanding that half the number of rounds were fired at a portion of the target "which was secured by these bolts."—*See* 2nd Report of Ballistic Experiments, by W. H. Noble, M.A., Lieut. R.A., and Associate Member Ordnance Select Committee, page 45.

With only one or two exceptions, *all* the ordinary bolts were broken in this experiment, and ordinary bolts in plates *not struck* were broken by the jar of shot striking the plate secured by the stretching bolts, and the portion of the target which was secured with stretching bolts was completely penetrated six times during this experiment.

The first shot (No. 933*) struck a plate entirely secured by ordinary bolts, and broke six armour bolts and two rivets.

Relative effects of Shell Firing upon the fastenings of two Warrior Targets secured respectively with ordinary Bolts and those of Major Palliser's pattern.

June 24th, 1864.—Warrior target secured by ordinary bolts 2 inches in diameter.

2nd Round.—Steel shell, 68 lb. 7 oz.; bursting charge 2 lb.; fired with a 14-lb. charge from Sir W. Armstrong's 70-pounder muzzle-loading gun.

Result.—" Nine armour bolts and one backing bolt broken."

June 27th, 1864, *2nd Round.*—70-pounder shell, as above.

" Twelve securing-bolts drawn from 1 inch to $1\frac{1}{2}$ inch; seven securing bolts " broken."—Report of Armstrong and Whitworth Committee, page 457.

This target is still at Shoeburyness, and although it was fired at by small guns (70-pounders), and only penetrated three times, nearly all the armour bolts are broken.

January 5th, 1865.—Warrior target, secured by stretching bolts, $1\frac{1}{2}$ inch thick.

No. 971.—Steel shell, 100 lb.; bursting charge, $3\frac{1}{2}$ lb.; fired with 25-lb. charge, from 7-inch 100-pounder muzzle-loading rifled gun; three rivets and one angle-iron broken; stretching bolts uninjured.†

No. 975.—Steel shell as above; stretching bolts uninjured.

No. 977.—Steel shell as above; stretching bolts uninjured.

No. 978.—Steel shell as above; stretching bolts uninjured.

No. 972.—Round steel shot, weight 105 lbs., fired from smooth-bore 9-inch gun, with 25-lb. charge. Rib and angle-iron broken and skin cracked; four wood bolts broken; stretching bolts uninjured.

No. 973.—Same as last. Struck close to old hole, both shot driven through; skin opened 3 feet 3 inches by 1 foot 9 inches. None of the stretching bolts broken; one of these bolts was pulled clean through the plate and remained unbroken in the skin in rear of the target.

No. 974.—Same as last. Struck close to an old hole, clean through; stretching bolts unbroken. *See* Table of Experimental Practice received by Ordnance Select Committee from Shoeburyness, on the 17th January, 1865. These bolts were made in the Royal Dockyard at Chatham.

* Every shot fired at Shoeburyness at iron plates is numbered and photographed. † This shell did not burst.

The two following experiments will shew the worthlessness of elastic washers of any kind on an *ordinary* bolt.

Captain Inglis's Shield.

Captain Inglis's Royal Engineers' Casemate Shield was fired at by an Armstrong 300-pounder, a 7-inch Whitworth rifled gun, a 7-inch Lynall Thomas rifled gun, and a 9-inch smooth-bore Armstrong gun, on the 3rd March, 1863.

The bolts in this experiment were 3 inches thick, or of four times the sectional area of $1\frac{1}{2}$-inch bolts already alluded to.

" Between the front and rear planks" of this target " sheet lead was introduced to " check vibration, and under the nuts of the screw-bolts elastic washers of various " descriptions were used. Some of these washers were of the nature of buffers composed " of 3 inches of india rubber inside a strong wrought-iron cylinder; others were coils of " wire rope similarly confined, and in other cases several lead washers and washers of " iron and brass were used."—See *Professional Papers of the Corps of Royal Engineers*, vol. xii., page 133. On this occasion six shot, fired from the above-mentioned guns, struck this target, and eight of these bolts were broken, although in no instance was the target, which for its weight is probably the cheapest as well as the strongest structure ever erected at Shoeburyness, penetrated.

Mr. Chalmers's Shield.

A wrought-iron shield, with a wood backing and inner skin, was placed in the right-hand embrasure of the granite casemate which was lately fired at at Shoeburyness. The securing bolts of this shield were 3 inches thick, or four times the size of the stretching bolts, and had thick india-rubber washers under their nuts. The shield was fired at by the 7-inch, 8-inch, 9-inch and 10-inch rifled guns, and struck thirteen times. Although in no instance was it penetrated, eighteen of these huge bolts were broken. Some wooden targets which were erected in rear of the shield were completely penetrated by the flying bolt-heads, which averaged about 6 lbs. in weight. In one instance a broken bolt, of upwards of 25 lbs., was thrown more than 18 yards to the rear. Had the gun in the embrasure been served by a detachment, every man must have been killed or wounded.

As both Captain Inglis's and Mr. Chalmers's shields are still in existence at Shoeburyness, the above account as to the number and size of the broken bolts can be verificd.

The American accounts of the first bombardment of Charleston shew that all the casualties on board their armour-clad ships were caused by flying bolt-heads.

The last occasion on which my bolts were tried was in the now famous 8-inch plated target, the whole of which was secured by them; and although this target was fired at with a score or more of steel and chilled shot and shell of 250 lbs. weight, with 43 lbs. of powder, from the 9-inch rifled gun, and although the target was repeatedly penetrated by my chilled white-iron shells, in no instance were any of the bolts broken except when the bolt itself was hit and driven clean through the target along with the shot.

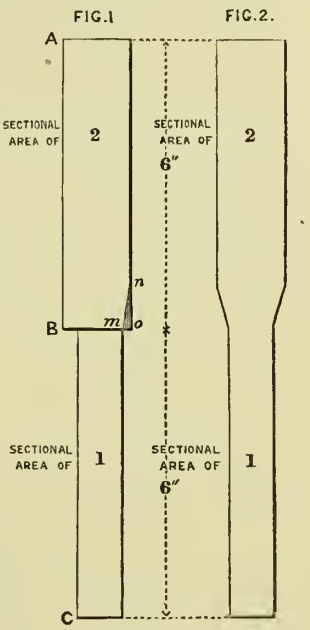
DISCUSSION.

The CHAIRMAN (Mr. Reed): We shall be very glad to hear the experience of Captain Heath upon this question, if he will be kind enough to favour us.

Captain HEATH: I think as the official reports have been quoted by Major Palliser, perhaps I may just carry them on one step farther. The system of Major Palliser is to allow the bolt time to stretch. Well, that may be done by any spring of any sort, and if you put a sufficiently powerful, and at the same time a sufficiently elastic washer of sufficient depth between the nut and the skin of ship, you act on Major Palliser's principles but in a different way. On the last occasion when bolts were tried, there were several descriptions tried. One was in that direction, and it seemed to answer—as far as one experiment is concerned—quite as well as Major Palliser's plan. More experiments are necessary to test the point. There would in that case be the advantage that your bolt would remain of its original thickness and its original strength, and after action the same bolt is available, with a fresh washer, while in Major Palliser's plan the bolt is stretched—not broken—and stretching means weakening.

Mr. BRAMWELL: Mr. Chairman, this is a subject to which I have had occasion to give some attention, and it seems to me that Major Palliser has devised, in reference to armour plating, that which in another shape for some years past was well known to engineers; but, although knowing it, I do not think they have applied it to bolts, nor do I think it has been so applied before its adoption by Major Palliser. Engineers have known for some years past the danger of having any sudden change of shape in iron structures exposed to sudden shock or to continuous vibration. For example, no locomotive engine builder in the present day would think of making, in the axles of the locomotive, projections with sharp corners; because, if he were to do so, there would be only a certain number of miles run by that engine before fracture must inevitably take place. Therefore, we are in the habit of putting in our specifications that, whether shown on the drawings or not, all collars or other projections shall be made with bold hollows to the angle, and that wherever there is a change of form to be made, that change of form must be made gradually, not suddenly. But, although we knew the utility of a gradual change of form as regards axles, &c., I do not believe we ever thought it was desirable to apply it to the bolts of armour plates till Major Palliser told us; and I believe, had he not done so, we might have gone on a long while without finding it out for ourselves; for, as a rule, the bolts used in engineers' work unite two surfaces of similar character quite tightly the one to the other, and are not subject to violent concussions. It may well be, therefore, that engineers might have gone on for years without applying to the subject of screw-bolts the

knowledge they possessed on the point when considered in relation to axles and other parts; but Major Palliser has shown us that the bolts which secure armour plates, although screwed up tight, may nevertheless, owing to the springing outward of portions of the plate when the plate is struck by shot at other parts, suffer a strain of impact of the character of that which he has so well illustrated by his experimental apparatus. Major Palliser has also on the black board given us a formula to shew the way in which the "work done" residing in the shot may be resisted by the extension of the bolt; but in the remarks he makes on that formula I think there is one point which is obscure, as Major Palliser says in effect, "If there are two different "areas in the bolt, and if the change from one of these areas to the other be "sudden, then the extension is made through practically only an infinitely "small space at the point of change of form;" but I must say I cannot look upon that as a satisfactory explanation, because it is difficult to see why the whole extension should be supposed to take place only at that one spot. Assume, for example, a shot that struck the armour plate caused a portion of it to spring outward with a force such that an extension equal to, say 12 units, must take place in order to absorb the "work done," and that this had to be met by a bolt like Fig. 1, with an area of 2 from A to B, and an area of 1 from B to C, then when the strain came upon the bolt to cause it to extend, why should not it do so throughout its whole length, but in the inverse proportion of its areas, that is to say, why, if A B be assumed of a length of 6, should not that extend $\frac{1}{2}$ per particle of length = area of $2 \times \frac{1}{2} \times 6 = 6$? While if B to C be of a length of 6, why should that not extend 1 per particle, or $6 \times 1 = 6$? making the total extension of 12; and why should it be assumed that the extension would be of necessity confined to an infinitely short length of the part B? It appears to me that such a view is deceptive; and that the fact is, extension varying with the area would take place throughout the length of the bolt, and would not be confined to a very short space with B; but I am perfectly sure that notwithstanding it would appear from the foregoing that sufficient extension would take place to absorb the "work done," nevertheless the bolt would very speedily break at the point B, while if it had been made of an uniform section of 1, and of a length of 12, it would have extended 12 without breaking, or if it had been made of an uniform section of 2, and of a length of 12, it would have extended actually a length of 6, but a value of section $2 \times \frac{1}{2}$ extension per particle $\times$ 12 = 12, and would not have broken; and further, if the bolt had been made like Fig. 2, *i.e.* like Fig. 1 with the mere difference of the gradual tapering off at B where the area changes, it would not have broken. I believe the fracture at the point B in Fig. 1 to be due to this, that the shaded triangle *m n o* of the large section must be made to extend along with the central part to which it is attached, and that this extension has to be mainly effected by the extreme outside part of the small section, which outside part has therefore a far greater strain per particle than its fair share, and is thereby caused to give way to a small distance in under that strain, causing a crack round about the junction of the small area with the large, such crack extending, as before said, only a short distance in; but short as the distance may be, it is sufficient to cause the *effective* projection of the large part beyond the small to be still greater, and thus the next time a strain comes on, the effect is much heightened, perhaps even to rupture; as it is manifest, if this explanation be the



correct one, the mischief would be rapidly accumulative. When, on the other hand, the corner is eased off, as shown in Fig. 2, it is clear that no such excessive strain could be brought upon the extreme outside particles of the small section. I think that the cause of fracture at the point B is to be found in the reasons above given, and not in the suggestion that because the bolt had two different areas of section, therefore the facility of extension in either section was at once stopped throughout the length of those sections, and was restricted to a mere line at B.

Mr. Barnaby: May I say one word in corroboration of what Major Palliser has said in connection with these bolts of his, arising from certain experiments which, as you know, we made some three years ago, after the bolts had been suggested by Major Palliser. Those experiments, which are illustrated in our last volume of *Transactions*, I think shew that what we have just heard is not quite true. The trials which are referred to there were made with bolts of the same size through a portion of their length as they were in the thread, and it was found that they broke with the same steady strain upon them, whether they broke in the thread or in the reduced part of the solid bolt, and, moreover, that they broke,—not in the shoulder, although the shoulder was turned suddenly, but in the middle of the reduced part, and that the reduction in area seemed to be confined to the reduced part of the bolt. This also appeared, that the bolt broke, when it had not been reduced, with an extension of something less than $\frac{1}{8}$ of an inch, whereas a bolt of exactly the same length—21 inches, when reduced in the middle for about 5 or 6 inches, stretched about $1\frac{1}{2}$ inch. These facts seem to me to bear out what Major Palliser has said this morning. It was considered at the time whether or not it would be a good thing to introduce bolts of that kind into our ships, and it was said that the difficulty of putting a bolt of that sort through wood which was required to be water-tight, was such as would lead to a great deal of expense in putting in the bolt, after it had been reduced, to fit the hole. Major Palliser has done it, and done it very successfully, but with a certain amount of expense. Instead of doing that, therefore, it was decided to adopt that mode of attaching the armour to the sides of the ship which has been referred to by Captain Heath, namely that of having an india-rubber washer under the nuts, which should give the elasticity required, and which should go back again, and would not allow any permanent stretching of the bolt. It ought to be known that the bolts, which have been referred to by Major Palliser as having broken to so large an extent in our targets, have not been bolts provided with these india-rubber washers.

Major Palliser: The bolts which attached the 6-inch plates to the old backing* were $2\frac{1}{2}$ inches thick. They were fitted with elastic cup-washers, and were fired at by the 7-inch gun, throwing 7-inch ogival-headed chilled shot. Every one but two broke. The bolts, which were subsequently fitted with elastic cup-washers, had very fine threads upon them, and I think the reduction of the area in the screw part was so small that it excites the extensibility of the remainder of the shank, and that it is only an approach to what I originally proposed.

Mr. Barnaby: You will quite understand that the point which Major Palliser has raised is a very interesting one. It is the question of how much we owe to the fact that we have put a finer pitch to the threads of the screws. This alteration in the pitch is in accordance with a suggestion of Major Palliser's, and a certain amount of benefit results from it; but it must not be carried too far. We are, however, of opinion—supported, I think, by what Captain Heath says—that the india-rubber washer

* This target was called the "Box Target."

has in itself very much of the credit which is due to the bolt which has stood well in the particular case that Major Palliser has alluded to. He, however, knows more about that matter than I do. I only know that the trials with the india-rubber washers have not been carried out, as against his bolts, at all completely yet. Just one word more with reference to a point of practical interest. The armour bolts which are now used are very much larger than those which were formerly used. There can be no doubt about great advantage arising from that. The manner in which the bolts in the Fairbairn target broke down, shewed us the disadvantage of using small bolts. (Mr. Barnaby then described the mode of tapping the nuts of screws now in use at Chatham, and by which—instead of making thirty or forty nuts a day—they were able to make about one hundred and forty. The plan, he said, was due to a foreman, Mr. Middleton, of Chatham.)

Mr. COWPER: I may mention that I was at Shoeburyness and saw the plates of the "*Fairbairn* target" nearly knocked off, long before the "*Warrior* target" was made. The bolts and nuts were very small, and few in number, and I had expressed my opinion as strongly as I could long before the trial, that they were out of all proportion to the armour plates. It was not a thoroughly mechanical job. The bolts should have been put in in proportion to the thickness of the plates, say 3-inch bolts, or $2\frac{1}{2}$-inch, to $4\frac{1}{2}$-inch plates. They were better proportioned afterwards, but all those small bolts broke. The nuts dropped off in all directions from the shock, as has been described. The extreme violence of the shock or blow on the bolt, arose from the fact, that when the armour plate was struck at one point, it bent or sprung outwards with excessive violence at another point, two or three feet away, and there broke one or more bolts. I then suggested to the Armour Plate Committee, spring-washers, though I do not for a moment set up the idea of spring-washers as a substitute for Major Palliser's form of bolt. The washers might be made of various substances, such as compressed wood, felt, or india rubber (and in a drawing I submitted I shewed ten inches of oak under the nut), which would give half an inch *elasticity*, whereas a long iron bolt, as a rule, would not give one-eighth of an inch *elasticity*. Then, unless the iron were very tough and uniform in quality as well as in section, the *stretching* or *permanent elongation* from excessive strain would occur chiefly at one place, and it would very seldom happen that in a 20-inch length you would get more than half an inch stretch, though once in an experiment I succeeded in stretching a link of a suspension bridge (the Kieff Bridge) $5\frac{1}{2}$ inches in a length of 7 feet 6 inches. I think that in the apparatus now exhibited by Major Palliser, there is great elasticity and want of solidity, though the experiments may be useful as comparative experiments. Of course the number of blows required to break the bolt will depend very much on the solidity of the apparatus. I think our best thanks are due to Major Palliser for bringing the matter prominently forward.

Major PALLISER: Here are half a dozen bolts which you may try, and you will find that they will all break at about the tenth time. I have tried it several times, and it is always about the same.

Mr. SCOTT RUSSELL: I would ask Major Palliser to be kind enough to give us the most definite answer he can as to the comparative value of the washer, and his elongated system. I would request him to bestow his attention in his answer upon that subject, because I am one of those who have all along admired extremely Major Palliser's invention; and I think Mr. Barnaby deserves the thanks of us all for having been one of the earliest to make experiments upon the applicability of that invention to armour-plated ships. But, while I admire extremely Major Palliser's invention, my difficulty is to know what is the degree of betterness in the one or the other—between his bolt and the washer. Now, in Mr. Bramwell's remarks there was a very important observation, in the value of which I entirely coincide,—

that where bodies are subject to concussive or percussive strains, or strains implying high velocities, the transition from a large to a small area should, as a general rule, be made in the most gentle manner. I only say that in order to avoid our drawing a wrong inference from the very remarkable fact stated by Mr. Barnaby, which merely goes to shew that that case of the Palliser bolt is a case in which some other cause of weakness comes near, and the cause of weakness that comes near is the diminution of area taking place in the centre of the reduced part, which does not at all invalidate the general correctness of Mr. Bramwell's remark, although it does appear in this case that the bolts did not give way from this particular cause. In another view of Major Palliser's arrangement about screws, the principle which Mr. Bramwell has enunciated is still more valuable. Major Palliser's invention of the application of plus screw instead of negative screw, if I may so call it, is of very great value. I say also, I think, as a general rule in the construction of machinery for a great variety of purposes, the use of plus screws, added on to the diameter of rods instead of minus screws cut off the diameters of rods, is of the greatest value; and I would say that one of the places where it is of high value is in the stays of boilers under high pressure, for there the nipping off of a stay is entirely done away with by the reduction of its inside. If Major Palliser will allow me, I would shew that I am not prejudiced in favour of his invention beyond the place where it is really valuable, by telling you where it is not valuable and why it is not valuable. In machinery it would be used to a much greater extent than it is likely to be if the things in which it was used were subject to draw only; but, as the same bolt in machinery is generally subject both to draw and to crush, we do not choose to turn away the centre, and the reason is this—that when the crush comes we want thickness in the centre that the rod may act as a pillar; and it is only when the bolt is disposed to draw that its durability, its reliability, depends greatly on the centre of the rod being more slender than the point where the screw comes. I would say, with regard to Mr. Bramwell's explanation, that what he said explains admirably why a bolt-head usually goes off at the first turn of the screw—because it is there that the abrupt transition, which Mr. Bramwell has pointed out, takes place.

Mr. Varley: I have had very frequent necessity for testing large quantities of iron wire, and I have noticed a curious solution of one of the questions which have been raised to-day; and that is—why the inequalities of the iron, as shewn by Major Palliser, do not cause the iron to break at that point. In testing the wire of the Atlantic Telegraph Cable, which consisted of homogeneous iron, we found that when the cable was hard drawn it was elongated only from a half to 1 per cent. before breaking. When that wire was softened down, it began to stretch with about one $\frac{1}{2}$ the strain that was necessary when it was hard drawn; but, instead of the stretching being confined to one little point—perhaps a quarter of an inch in 50 inches—it was extended into a long mass, because the rate of increase of strength upon the wire, due to the hardening and stretching, was greater than the diminution of the diameter; and whilst that condition lasts each portion as it stretches hardens that portion, and gives it a great tensile strain, and so there is a strain out of proportion, and therefore the point should be soft, unless the annealing is just such that the hardening of the iron gives it great strength at that particular point.

Mr. Scott Russell: I will just ask this gentleman whether he has the least idea of what the nature of this hardening is. It is a remarkable phenomenon—the hardening which the stretching gives to it. What I want to know is, what the hardening is? How it takes place by stretching?

Mr. Cowper: I can explain in reference to steel wire. If the wire is soft—more especially steel wire—and then it is drawn several times, the surface of the wire becomes hardened. It is as though you

burnished it very hard, and then the outside of the wire is harder, and will not stretch so much as the inside of the wire; and if you break it, you will find the crack on the outside, and if you look at the fracture, you will find that the internal portion has been pulled out, as it were, leaving a kind of cup. If you harden the wire, and then draw it, it will draw very well, and that is the way in which the hard steel wire is now made for ropes for traction purposes, as well as for steam ploughs, and I think that the steam plough would not exist if it were not for that hard steel wire rope.

Mr. Scott Russell: I must take objection to one point. I am not sure that the hardening stops at the skin. I have made several experiments in stretching wire, not drawing it, because in the process of drawing, it does harden the skin. I have made several experiments in stretching wire without drawing, and I have stretched soft wire by mere tension until it has become, as this gentleman described, perfectly hard—tempered and brittle. This was done by the mere act of elongation. It is a very remarkable phenomenon, and I should be very grateful for any explanation of it.

Mr. Varley: If I am not out of order, Sir, I would answer the question which Mr. Scott Russell has put to me. The effect of the sudden stretching of wire is to produce heat, and it is well known that iron wire that is hard drawn, upon being annealed, is enlarged by that operation, and it is most probable that the increase of strength is due to the greater closing of the particles. I ought also to mention, that this hard wire, which is of excellent quality, stretched but one per cent. when hard drawn, but when it had been softened down it would stretch as much as from 30 to 33 per cent. before it broke. That, of course, indicates how much the wire was reduced in sectional diameter by the elongation. It bore, on the average, when hard drawn, from 950 to 1,000 lbs. When it was annealed it began to stretch at 47 tons, on the average, and its strength increased from 700 to 750 lbs. before it broke; shewing how tremendously it hardened and strengthened by the stretching. What I wished to draw attention to was, that if you make your bolt too hard, then its weak point will be the source of the flaw; if you make it so soft that the hardening due to the stretching leads to the reduction of area, then the whole bolt must stretch.

The Chairman: (Mr. E. J. Reed.) Before Major Palliser replies to the observations which have been made, I think it is due to him to say how valuable his Paper has been, and what a very valuable discussion it has raised. Major Palliser, no doubt, labours under the feeling that his bolt has been a long time invented, and not much used; and that the Admiralty, in this, as in most matters, according to public opinion, is slow. Well, some grounds for the slowness have been exemplified in the discussion of to-day. But I should not like the Paper to pass, nor Major Palliser to close the discussion, without saying that we have not any prejudice at all against this bolt, and that, if Mr. Palliser will, by one of those compromises which are in fashion in these times, and in all other times, approach us in our difficulties, we shall be very glad indeed to try or to use the bolts. Great value ought, however, to be attached, and is attached, to the elastic washers, which, as Captain Heath has intimated, have been signally successful. With the spring washer we have got extraordinarily satisfactory results, and Major Palliser is in the position of having to compete with a very different bolt from that which existed when he commenced. I can only say, that in this matter the importance of it is thoroughly realised, and that armour plate fastenings have received, and are receiving, most careful consideration, and there is no desire anywhere, I am sure, but to adopt that bolt which is proved to be the best. Captain Heath, and his colleagues, have a little responsibility for not having given us yet, at the Admiralty, reports which we have been trying to get on

these bolts. We are waiting for one report in particular, and when we get that, we shall be in a little better position. You will excuse my mentioning it. (*to* Captain HEATH.)

Captain HEATH: I think you must have had it at least two months. There were three sorts of bolts tried. That was fully three months ago, and it was reported on two months ago, and passed out of our hands to the War Office, and no doubt it must have been sent to you in duplicate. It must be on your shelf.

The CHAIRMAN: No; we have received the last report, but there is a previous one we have not yet had.

Captain HEATH: You will find that we are quite free from all blame. You have it somewhere, I assure you.

The CHAIRMAN: I think we are almost as much indebted on this occasion to those who have engaged in the discussion as to Major Palliser himself, for the whole proceedings have been most valuable and interesting. I am sure we are very much indebted to Mr. Bramwell and the other gentlemen who have given us the benefit of their experience.

Major PALLISER: I do not know that I have much to answer. When I used the term "infinitely "short," I think I added "theoretically." With regard to what has been said about elastic washers allowing an ordinary bolt to remain of its original thickness and original strength, I would observe that the strength of an ordinary bolt, when subjected to a *statical* strain, depends upon the area of that part of the bolt which is reduced by the screw thread, and therefore the bolt will not be made at all weaker by reducing its shank down to the same size as the screwed part. I have some further experiments here which I did not quote, and I think I cannot do better than quote them now and append them to this Paper.

Mr. BARNABY: Had they cup washers?

Major PALLISER: Chalmers's had not; but the others had. The bolts in the "Box target" were fitted with elastic cup-washers and were nearly all broken. They were $2\frac{1}{2}$ inches in diameter, and were screwed with the ordinary "Whitworth" thread. The bolts which were fitted with various natures of washers, and which were made *subsequently*, were screwed like mine with *very fine* threads. The reduction of their area by screwing was in consequence so slight, that the ultimate strength of the screwed part was greater than the resistance, within its elastic limit, of the shank of the bolt. Hence, the shanks *did* stretch; and the previous fracture of nearly all the $2\frac{1}{2}$-inch bolts, fitted with elastic cup-washers, but screwed with ordinary screw-threads, proves that the success of those subsequently tried was due rather to the diminution of the difference of strength between the screwed and unscrewed portions of the bolt, than to the elastic washers. I would point out another thing, and that is, that these elastic cup-washers have not been subjected to so severe a test as the stretching bolts which were fired at by the round-headed shot, inasmuch as when the former were tried ogival-headed shot were employed, which do not drive the backing of the target against the inner skin to the same degree as round-headed shot do. I think some gentleman said that a bolt which was 20 inches long would only stretch $\frac{1}{8}$ inch; but if you will examine the bolts that have been tested in your presence, you will find that they have stretched one-third of their original length.

Mr. COWPER: I said that a piece of iron will never have more *elasticity* than $\frac{1}{8}$ inch in 20 inches,

though it may *stretch* and permanently elongate much more; the 7-feet-6 bar I spoke of had just $\frac{1}{8}$ inch *elasticity* both *before* and *after* it was *stretched* $5\frac{1}{2}$ inches.

Major PALLISER: What you say is quite correct. The bolt with the reduced shank will stretch if the strain upon it exceeds its elastic strength, but it will not break unless that strain be exerted through a distance greater than the one through which the iron will stretch. I do not think I have anything further to say.

ON THE APPLICATION OF THE "CAPONIÈRE" SYSTEM TO SEA-GOING SHIPS OF WAR.*

By C. W. Lancaster, Esq., Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; E. J. Reed, Esq., Vice-President, in the Chair.]

The object of this Paper is to offer, for the consideration of the Institute of Naval Architects, a proposition which it is believed presents some novel and important features; and it seeks to shew that it may be possible to construct vessels on this plan which shall combine, in a greater degree than any heretofore designed, all the advantages of the "Turret" system, as well as those of the broadside construction.

The published *Transactions* of the Institution supply, in the very careful and forcible Papers furnished by the Constructor of the Navy, every argument that could be used in favour of the broadside system, and the Papers of Captain Cowper Coles also give the most ample testimony to the many points of advantage of the "Turret" system.

It is therefore unnecessary in this Paper to make any further allusion than a respectful reference to the statements supplied by both these gentlemen.

Without further preface, it is now sought to direct the attention of the Meeting to the peculiarities of the proposed design. The drawings submitted represent a vessel of the *Hercules* class to mount eight 600-pounders, four on each side.

In the construction of the hull proper, four semi-circular projections, two on each side, as shown in Plate VII., Figs. 1, 2, 3 and 4, are framed in a substantial manner, and worked in with the rest of the hull; the thickness of armour-plate to be left to the discretion of the authorities. A horizontal port-hole, sufficiently large just to free the muzzle of the gun, is left in each "Caponière" or semi-circular projection, supported in the centre by a very massive solid wrought-iron pillar or shield plate, 2 feet 6 inches wide, and passing completely in-board and firmly secured.

* Received 4th April, 1867.

Without referring further to the details of construction, other than those supplied by the drawings, attention is now called to the system of mounting the guns, which are placed upon a turn-table in the manner proposed by the author to the War Department in the year 1852, as the original drawings exhibited prove.

This turn-table is furnished with a vertical port-hole for each gun—a belt of armour extending round the turn-table so as to completely cover the exterior horizontal port-hole, except at the points occupied by the muzzles of the guns.

The method of mounting the guns has now to be considered.

The proposition it is owned would be untenable without what is termed muzzle-pivoting; that is, the elevation and depression of the gun in-board, by making the gun describe a radius from the muzzle of the gun, the muzzle itself remaining fixed. The Plates and Model supplied by Mr. Mallet fully shew the simplicity with which this principle has been worked to a practical solution.

Having thus briefly described the dominant principles involved in this proposed system of construction, the advantages and disadvantages must be next considered.

On the one hand, it is claimed that this system possesses the advantages of:—

1.—Greater arc of fire than any known system. Two guns can fire ahead or astern at the same time, not only in a line with the keel, but will cross their fire at 100 yards in front of the stem or stern, and without any interference with any form of rig that may be considered desirable for sea-going vessels.

2.—By this system four 600-pounders can be fought simultaneously on each broadside, or either quarter.

3.—This system secures in-board loading; and in the act of loading the armour belt of the turn-table closes the exterior port-hole perfectly.

4.—The weight of iron employed would be no greater than with two "turrets."

5.—Any size of gun that can be worked or used in a turret can be used with this system.

The disadvantages urged against the system would appear to be as follows:—

1.—The extra width given to the vessel, and the absence of any docks possessing gates sufficiently wide to allow first-class vessels of this description to enter.

2.—It has been urged that it would interfere with the strength of the vessel.

3.—It has been thought that if these "Caponières" were struck by a very heavy shot, there would be a risk of jamming fast the turn-tables.

Examine each of these objections:—

1.—The country is now engaged in the enlargement of our dock accommodation. There can be no difficulty in so arranging the dock gates as to suit the largest vessels constructed on this principle.

2.—It is not thought by the author of this Paper that this objection has much force, because the vessel would be so constructed that the parts E and F would be designed merely for the accommodation of the crew and officers, and not in any way trenching upon the strength or efficiency of the vessel, which, in construction, would be substantially the same as the admirable specimens supplied by the Constructor of the Navy, save and except that the deck, fore and aft the iron bulkhead, would be recessed along its whole length.

3.—It is contrary to the conviction of the author that such would be the result of the impact of every shot, owing to the fact of the turn-table having a massive iron armour-plate belt, the effect of which would be to prevent the sides of the "Caponière" being driven in at all; but, assuming that they might be, even in this extreme case there would be no difficulty in an in-board mechanical arrangement which would allow turn-tables, circular racer, and every detail of the guns to be retired 5 or 6 inches, or even 1 foot further in-board, so as to release it from any jam.

Having thus, in the briefest manner, brought to your notice the leading principles embraced in this system, it is left to the consideration of the Meeting to determine how far they may or may not be points of advantage to the country and to the service; but it is impossible to close this Paper without tendering the author's grateful thanks and acknowledgments to the Department of the Controller of the Navy, for the patient investigation and kind assistance rendered, from the moment the plan was officially submitted some two years ago, up to the present time.

DISCUSSION.

Captain HEATHORN: May I ask Mr. Lancaster what advantage this appears to have over the turret system? I would remark that it appears to me that there is no very great advantage over the turret by this caponière system, and there are one or two things which struck me upon first looking at the matter as being rather inferior to the turret system. In the first place, these caponières, at the salients of his redoubt in the middle of the ship, appear to me to be heavy structures, and would make a vessel roll very much. I do not understand much about ships myself, but I believe there is at the present time, amongst people who do know something about them, some doubt as to whether heavy guns would

be able to work in the broadsides of vessels on account of their positions, and I believe that putting all the weight in the centre is one of the great advantages of the turret system. But here we appear to have all the weight of the guns put on the side of the vessel, as in the broadside system, with the extra weight of all this heavy plating and turn-table arrangement with which they are fitted. And here, again, there appears to be some difficulty in firing fore and aft with these turn-tables. The aperture would also, I think, be open to the objection of giving great weakness to those shields, although they have a strong support in the middle of them, which again at certain positions would interfere very much with the firing of the guns. Again, I do not exactly see how depression is provided for. I think this is all I have to say.

Captain HEATH: I should be sorry that this discussion should be closed without some individual opinion being propounded, on which I wish my brother officers, in some way, would help discussion. But there are two points that strike me. One is that those long slits which take the place of the ordinary ports must, as a matter of vital necessity, be provided with some sort of port or mantlet. Very recent experiments have shewn that guns in contiguous turrets, pointing at a convergence of only 20°, cannot be fought. The concussion to the one turret by the firing of the gun in the other was so great that the guns could not be loaded. Now, if the guns in the foremost turret there, as well as the gun in the aft turret, were pointed towards the port quarter of the ship, the men in the aft turret would be so seriously—I will not say inconvenienced, for it is a great deal more than inconvenience—would be so hurt from the concussion by the firing of the foremost guns, that I have no hesitation in saying that they could not fire. This is a point of very great importance for the consideration of those who advocate turret ships, and still more double-turretted ships—ships with more than one turret; more especially as it is supposed that you are to turn your turret away from the enemy while you are loading. In the heat of action, more especially in a general action, where you might have to fight in different directions, it might possibly happen that you might have one gun pointing in one direction, and another in another direction; and when that occurs, the one would damage the other. Then as to muzzle pivoting—it is a very desirable thing to try it. The principal drawback to it has been the great height of deck necessary. In fact it requires upwards of 9 feet to give extreme depression. Mr. Lancaster has shewn us that he requires the gun to be raised 9 feet above the deck. Then that entails difficulty in sighting and in taking aim. In no muzzle pivoting can you take aim except in a turret. The turret has got over that objection; but one of the difficulties in broadside ships is the difficulty of reducing the port and yet being able to take aim.

Captain SYMONDS: I think, Sir, with all due deference to the author of the Paper, that he might get nearly the same, if not equal results, by the very reverse of the system which he has proposed; and with your permission I will make a rough sketch of the way in which I think he might do it. I intended writing a Paper on the subject myself, but have been prevented. I believe one of the principal objections that have been raised to the broadside system is that the weight is too much on the broadside of the ship. Now, I think the plan before us rather meets that difficulty. The method by which I should propose to obtain nearly the same end as Mr. Lancaster, is similar to that which is referred to in the Paper I read last year.* By recessing the port in this manner by 18 inches, or even one foot, you get an arc of training of 90°, instead of 60° as at present—a point of very great importance, I submit. Supposing four 600-pounders were placed in a battery of this construction, we could obtain the fore and aft fire at either

* *See* Vol. VII. of the *Transactions*, Plate VIII., Figs. 8 and 9.

end by the indented side, and by recessing in the manner described, and at the same time fire on the broadside. You then have these embrasures, with 90° arc of training, making the fourth gun, which I am quite satisfied will require a much simpler and lighter construction than Mr. Lancaster's, and will also occupy less length and very much less weight. If this is gone into, I am sure, in calculating these turn tables, you will find that the side in my case will be absolutely lighter than it is in that; and in this case the line there (pointing) will be very nearly the same, without the disadvantages pointed out by Captain Heath. In addition to that, these guns, being retired from the side, have another advantage, that they do not project out beyond the side of the ship, and therefore are not liable to be hurt by raking fire as at present. But what I consider a matter of much greater importance is this:—If we look at the section of the ship, that (pointing) will represent the recess shown here; that will shew the port, the gun projecting slightly beyond the port; the pivot under the recess will give you a much better pivot than you have in an ordinary broadside ship. The amount retired from the side in this case will shew five feet. You will find that this is tantamount to being two feet higher out of the water, so that in rolling, a gun retired or recessed in this manner will have a great advantage over any gun which would be on the side of the ship. The caponière system would also require a wider dock than a ship on my principle, as the caponière projects. I regret very much that I have not provided diagrams, seeing that I had some prepared. There is another point in which I think my method has an advantage over the caponière, *viz.*, your gun is kept ready to work without closing your ports. In my plan, the port will be less than the ordinary broadside port, with this advantage, that instead of having the port cut away, and therefore representing a weak part, there is no angle in mine which may be knocked off by a shot, this part being rounded. The orifice or aperture will be considerably larger than the ordinary port, being closed when the gun is not required. I propose to make this sufficiently strong to make a fair and tight side when the guns are out, so that when the ship is rolling, we will say from 20° to 25°, with the lower half closed, which represents 11 feet 6 free-board, the gun may be run in, sponged, loaded, run out, and pointed with the port up, therefore not only keeping out the water if she is rolling, but protecting the men to a great extent from small arms or grape-shot. The upper port would be shorter. The advantage of retiring your guns will be, I think, perfectly appreciated by those who have opposed the broadside in their support of the turret system, on the plea of centralizing the weight. Perhaps in a very large ship, the recess may be only necessary to get the increase of 30° training, which I think a very important point, but in a smaller ship you may recess those guns five or six feet, and you may have guns of any weight working on turn-tables at these ports in the same way as you may have them in the caponière. There are other advantages in the securing of the gun which have before been pointed out by some of my brother officers, and which I have not had time to go into yet, but which I hope on some future occasion to be able to describe at much greater length when the thing is more perfect. But I submit that in a vessel of that sort you may place the same armament in a much better sea-going ship, and have all these advantages without any of those drawbacks which I have attempted to describe.

Captain HEATHORN: May I venture to remark that I think this last gentleman, Captain Symonds, gets more depression than Mr. Lancaster does.

Captain SYMONDS: The same depression as in an ordinary broadside; 7° is the depression I have given in the plans I have made. This admits of the guns being elevated 10°. I shall be very happy to shew you the plans, which will, perhaps, satisfy you.

Captain HEATHORN: It does not appear to me that you could do it so easily.

Mr. BARNABY: The plan proposed by Mr. Lancaster seems to have two great and evident advantages, the one being that of working very big and heavy guns upon the turn-table, and the other, that of being able to get a right-ahead and a right-astern fire, which no turret ship, that I know of, appears to be able to get. The point to which, however, I should like for a moment to allude, is one to which reference was made yesterday by Admiral Elliot, namely, the turret system as it affects the rolling of ships. It is supposed by a great many naval officers, and it appears to be an opinion entertained by the gentleman who has just spoken (Captain Heathorn), that one great disadvantage of the proposed system would be that the ship would roll very heavily. Now, I think I am safe in saying that a ship could be designed on that principle which should not roll more heavily than a ship having a turret in the middle. There is really no disadvantage in the broadside system as compared with the turret system in that respect. If you understand the principles upon which the rolling depends—and I think after the Papers and discussions we have had here we know something now about them—we may fairly say that a naval architect ought to be able, whether he is dealing with a broadside or a turret ship, to make it equally good in a sea-way. In the Paper I had the honour of reading yesterday, I gave the results of several of our iron-clads. I think you must have observed that the only turret ship which I was able to compare with broadside ships rolled the worst of any, and that the best ship of all was the broadside ship—the *Achilles*. The performances of that ship were such as it seems to me no ship can be expected to excel.

Mr. MARK H. ROBINSON: In reference to Captain Symonds's plan, may I ask whether the weight would not be equally well thrown into the centre, simply by recessing the whole side of the battery instead of recessing the port only, which, it seems to me, on his plan would act as a funnel for shot to enter by.

Captain SYMONDS: But you would not get the additional 30° on the straight side. You would be no better off than you were originally. The great object of the recess is to obtain an additional arc of training of 30°; the other advantages have occurred to me since, but that was my object in inventing that plan. It does increase the weight slightly—very slightly. As you observe, the whole thing falls inboard, and, therefore, brings that slight additional weight inboard.

Mr. MARK H. ROBINSON: I scarcely like to speak again; but it does seem to me that Captain Symonds's port has very much the same effect as the ordinary broadside port. It seems to me that guns might be trained to more than 60° on the broadside port by some alterations of the carriage and the plane. I say this in defence of the broadside system, although with my heart and soul I should go against the broadside system. The various plans suggested in opposition to turrets, but intended to obtain the same results, in the end resolve themselves into the broadside system, with much excess of weight, and little corresponding advantage. All plans proposed for combining the two things are illusory. The question has really to be fought out between the turrets and the broadsides—both in their simplest form.

Captain SYMONDS: This plan was not intended in opposition to the turret system, but only as an improvement upon the broadside system. The greatest amount of training that can be got on the straight side is 60°; but if the side is recessed you can get 90°. One foot recess will give the additional arc of training. There is no advantage in the way of centralisation, but it simply enables you to turn your gun in a greater arc than at present is practicable.

The CHAIRMAN (Mr. E. J. Reed): I wish to say, with regard to the remarks of Mr. Robinson, that it does appear to me that the throwing in of the side to the position of the port, has the greatest disadvantage which befals a broadside port when it is made large, for a large arc of training. The port, although ostensibly small is really very large. If you take an ordinary broadside port, the only means by which you can give it an additional arc of training is, of course, by enlarging it on the inside, and although you may do that without greatly enlarging it on the outside, still it is obvious that the actual port must be very much larger than usual. Captain Symonds's plan has certainly the advantage of making the port strong up to its full dimensions. There is nothing illusory about that—it gives a strong side to the port instead of a weak one, and you thereby get a greater strength added to the recession of the side, and that gives an arc of training greater than you can possibly get with a straight broadside.

Mr. MARK ROBINSON: I wanted to know one thing—would not that port act as a species of funnel?

The CHAIRMAN: I was going to say, the only point on which I had any doubt, and one which would require consideration, was whether it would act as a funnel. I should like to say that the reference which Mr. Barnaby has made to his statement of yesterday ought to be sufficient, I think, if not to dispose of the objections which naval officers frequently make, at any rate to cast grave doubts upon the accuracy of the opinion expressed as to the centralization of the weight. If it be a fact that the turret system is so very favourable—so necessarily and intrinsically favourable—to steadiness, please explain how it happens that turret-ships roll more than broadsides, and that too when in company with broadside ships which are distinguished by their rolling. That point must be cleared up; another point ought not to be lost sight of, and that is that the system which Mr. Lancaster has been proposing, and the system which Captain Heath proposed a day or two ago, and other systems which are associated, more or less, with broadside guns, do actually provide what turret ships actually do not provide, and that is fore-and-aft fire from behind armour; and it is a little singular that the perfect turret ship, which is now being built, namely, the *Captain*, designed by Captain Cowper Coles himself, under *carte blanche*, as was told us by our President yesterday, is a ship which will be distinguished amongst the ships of the British Navy as being incapable of firing a single shot ahead or astern from behind armour. Another circumstance has come into some notice, namely, that not only is that the case in turret ships in which there are poops and forecastles, which interpose themselves between the bow and stern-fire and the line of fire; but it is also the case in ships in which the sea-going properties, which you will undoubtedly get from the poops and forecastles, are sacrificed for the sake of head fire; and yet head fire is not obtained. I was told by an officer, who was commanding a turret in time of war—which is not a bad test of any principle, I presume—that, although when he was appointed to his ship, he eagerly accepted the appointment, in the belief that he was about to get a ship which would have the very desirable quality of being able to fire round in all directions, yet he found, when he came into the command of his ship, that he was practically in command of a broadside ship. It had the same disadvantages; and it was a very limited range of fire indeed which he could get without shooting away the anchor-gear, and a number of the essential parts of the vessel which he could not afford to dispense with, because he had frequently to anchor and to weigh anchor, and to expose himself, in fact, to circumstances in which he could not afford to dispense with those things. He freely admitted that if he were going to fight but one general action and have done with it, he would have got bow and stern fire; for he would have sacrificed the other things for the sake of winning his action; but as he had to perform quite another species of warfare, he was incapable of making this sacrifice, and the consequence was, that in the turret

ship he was absolutely without anything like fore-and-aft fire at all, and in very embarrassed and restricted circumstances; and even more than that, because his bow-and-stern fire had been nominally, but not really provided, he had to incur all the disadvantages in point of sea-going properties, which follow the dispensing with poops and forecastles; and he was, practically, under circumstances of very great importance and moment to him, actually hindered from performing service, because his vessel was deficient in those sea-going qualities which the poop and forecastle might have provided him with to a great extent. So that even when these sacrifices are made, when you preserve the all-round fire nominally at the expense of the sea-going qualities, you fail to get your all-round fire; and when you sacrifice your all-round fire for the sake of sea-going qualities, you do not always find that you get very pre-eminent sea-going qualities. There have been turret ships tried which have been as unsuccessful as any broadside ships which have ever been designed or produced. I only say this because it is not fair, it is not wise, and it is most pernicious to the turret system itself to advocate it upon a false basis, and to put it forth under false pretences. I presume no gentlemen here, or likely to come here, can be insensible, or ever have been insensible, to the extreme value of being able to bring your guns upon your turn-table upon every part of the horizon; and nobody can doubt that if the turret principle meant that, and nothing else, it would have been gladly and cheerfully adopted long ago by everybody. I can only say now, what I have much pleasure in saying after suffering years of obloquy, on the understanding that I was opposed to the turret principle,—I say that I was the very person, the one person in the country who was the first to favour Captain Coles by supporting that system in the scientific press, with which I was engaged at that time, seeking for it that which every system is entitled to, namely, a thorough and an impartial consideration; and all I have ever done in opposition to the turret principle has been to do what I have now done, to make certain statements which really must be considered. I make them only on the ground that if any one were to base a new system on pretensions which were invalid, and would not bear investigation, I should be bound to resist it. I can only say that I have not the slightest desire myself to perpetuate the broadside system, which, as you all know, is not my system. It is no invention of mine to fight guns on the broadside. I have no desire to perpetuate that system to the exclusion of turrets or of caponières, if they can be shown to be of greater value; but I do believe myself that the direction in which Captain Symonds has worked is a more promising direction than the other, and I believe so for this reason—that you can, in a broadside ship, or in any ship if you will content yourself with putting a port in large enough to give an arc of training of 90°, you can command a stern or bow fire. Now, you must do that with a certain sacrifice, perhaps, of indentation in the ship's upper works, or with some other compromise. I will not say without compromise; the turret system demands and involves compromises. All I say is that it is perfectly unfair and erroneous to imagine that the broadside system is opposed to fore-and-aft fire, if you will only make the same compromises in it which you have to make in other cases. I speak subject to the knowledge and feeling of the naval officers present when I say that if they would like to have a gun in a ship effectually plated, with the gun on a single pivot, with an arc of 90°, at the bow or the stern as the case may be, that can be done on the broadside principle if compromises are made in its favour. I am quite sure that, whether we agree fully, or in part, or not at all, with Mr. Lancaster, we all very much appreciate his kindness in reading the Paper which he has placed before us, because I am sure it must bring out into prominent light the clever working out of a system which must have interested any who have thought about it. I must confess that in these systems it often happens that gentlemen who are not shipbuilders do not see difficulties where we do see

them. It may arise from an indisposition on our part to improvement; it may be that we are, to an undue degree, obtuse; but it may also arise from some well-grounded apprehension of difficulty. I am sure we are very much obliged to Mr. Lancaster for his great kindness in reading this Paper.

Lord LAUDERDALE: Having been connected with the Committee to investigate and to give an opinion on the turret system, and they having recommended that a sea-going turret ship should be tried, I wish it to be understood that when we gave that recommendation we meant a vessel of the description of the plan which was laid before us, which had neither poop nor forecastle, and upon that plan the turret had more training forward than in any other. As I understand and believe, the vessels which are now being built are very much larger than in the plan that was laid before the Committee, and they have poop and forecastle, which, in my opinion, alters the thing entirely. Every naval officer knows the difficulty of hitting a vessel which is low in the water. If the vessel is high, there is no difficulty in it. Still, the great advantage of the turret system in the plan laid before us was, that she was lower than any other vessel, and there was great difficulty in hitting her, as far as elevation goes. But all that is done away with, if you put a poop and forecastle, and build the vessel up. Again, the turret system, I think, is far better than Mr. Lancaster's plan. I will not say whether it makes the vessel roll more or less, for all vessels will roll. Naval architects tell me—"Oh! here is a vessel that will not roll, and I will build you "another the same," but when the vessel is built, and she comes to be tried, she very often does roll, and you cannot stop her. But I will say that if you put the guns in a turret in the centre of the ship, whether it makes her roll more or less, you will be able to fight the guns in the turret, which is in the centre of the ship, when you cannot open the port in a broadside ship. I am afraid that Mr. Lancaster here, in putting his turret on the broadside, goes at once into the disadvantages of the broadside system. I have nothing more to say, Gentlemen, except that I wish you to understand that any vessel that may be built upon the turret system, with a poop and forecastle, and high enough out of the water to be a wholesome sea-going ship, is not the plan we recommended to be tried. I will not say that that plan which was laid before us would have answered, but the opinion of the naval officers and architects was so divided, that we thought it would be better to go to the expense of having one vessel to set the point at rest. There can be no doubt about it, I believe, that for simple harbour defence, a single turret ship, built something upon the American *Monitor* system, will be of great advantage.

Captain HEATH: Will you allow me to add one word more? I believe that the next battle will depend very much upon small guns, and I think that in all our armour-plated ships no provision is made for that. I believe that the number of large shots fired in an action in future, will be far less than the number of large shots fired in the old days. The danger, therefore, to naval life is far less, and will be far less than it ever was before, but I cannot see why, where there are no armour plates, there should not be small batteries to protect the musketry firing at the ports. In that view Captain Symonds' plan will evidently be a very bad one. (Captain Heath went on to illustrate his remarks by some diagrams on the black board, without which his further remarks would not be understood).

Mr. GALLOWAY: Will you permit me to say two or three words?

The CHAIRMAN: There is not the slightest objection to your speaking to the subject, but there is to your speaking upon anything else. If you will address yourself to the subject you may speak.

Mr. GALLOWAY: The disadvantages of the turret system have been made quite clear by the remarks of the Chief Constructor of the Navy. I believe that in a proper fighting ship there must be necessarily a

combination of the turret and broadside principles, and I assert that that is to be obtained. I have a plan in my head which I will produce some day, but I intend keeping it a little longer.

Captain HEATHORN: There is now being exhibited in the Paris Exhibition such a plan as Mr. Galloway has named.

Mr. LANCASTER: I have not the pleasure of knowing the name of the first gentleman who spoke, but the first question he mentioned was—What are the advantages of this system over the turret system? If you will allow me I will point out what I believe to be the advantages of this system of construction. On this construction you can fight four guns on either side simultaneously, that is to say, having eight guns, four on either side, you can fire four guns on either broadside on each quarter simultaneously, and two guns simultaneously ahead and astern; I do not believe that with any arrangement of the turret principle that is possible. I have never seen any design which would enable you to attain the same amount of fire. Captain Heath mentioned a very practical point, and that is the apprehended danger to the men at the other port holes. I have observed myself at Shoeburyness, the number of times I have had the honour of attending there, the very bad results following the firing of heavy guns to the detachment of men. In fact, I myself, personally, have experienced those bad results. Even at the distance of five and twenty feet, the rush of air from the heavy guns is enormous. I am perfectly convinced that the matter will be a very serious one to the men who are loading heavy artillery, if they happen to be at the next port, or in the immediate neighbourhood, at the time when the gun is fired, especially the 22-ton guns. I feel sure that many casualties will be occasioned to the men loading the next gun. I would venture to submit to Captain Heath that this lateral port-hole is closed by interior armour, so that when in the act of firing this (pointing) would be absolutely closed, and no such casualty could occur, and it especially provides against the very objection which the gallant gentleman has made, as the guns are loaded inboard.

Captain HEATH: I must have misunderstood you. I had no idea that you had any machinery for closing it. I did not see it in the diagram.

Mr. LANCASTER: None of this lateral port-hole is open, except just the part occupied by the muzzle of the gun; everything else is hermetically closed, and therefore no rush of gas from the firing of the other caponière can possibly interfere with either the pointing, the firing, or the loading of the gun. Another thing which Captain Heath also pointed out was, that there is a difficulty in pointing the gun. Now, with all submission, I think that if he reflects he will see that, these guns being put on turn tables, there is practically no more difficulty in taking aim from a turn table at the side than there would be in an ordinary turret. The same thing is applicable.

Captain HEATH: The size of the port affects the question, not the machinery for turning the gun.

Mr. LANCASTER: Yes, the same machinery can be applied as in the turret.

Captain HEATH: But you must use your eyes; you cannot point the top of your deck. The turret itself is pointed, not the gun; but in your case you point the gun.

Mr. LANCASTER: In this case you would point the turn table from the upper deck. You could not take the sight over the top of the gun, but you could take it from the side of the gun.

Captain HEATHORN: But your port is shut.

The CHAIRMAN: You have an aperture the other side of the gun—away from the gun.

Mr. LANCASTER: Then, in reference to the very lucid explanation of Captain Symonds, with regard to his plan of indenting the side of the vessel—the only thing I fear in reference to that is, that the same result would occur as has happened at Shoeburyness. I do not know whether attention has been called to it lately, but some three or four years ago—I think I am correct as to dates—the Royal Engineers carried on experiments with some embrasures, one of them supplied by the Mersey Iron Company. It was not indented so much as that, (pointing) but it was practically indented like that one. It is down at Shoeburyness now. When the Committee fired Shrapnel's shell, and indeed iron shot, at those embrasures, the number of pieces that broke up and entered the port-hole was nearly ten times the amount at ordinary times. Acting like a funnel, that would be the natural result, I should fear. I am not aware that I have to answer any other point. I would only generally ask that the Meeting will at their leisure consider this plan which is now in their hands; and perhaps, at some future day, I may have the happiness and pleasure of seeing attention given to it, to see if there is anything in it; and if there is anything in it, I hope it will be of use and advantage to the country.

FURTHER EXPERIENCES IN MARINE ENGINEERING.*

(*In continuation of a Paper read 7th April*, 1865).

By Robert Murray, Esq., Associate.

[Read at the Eighth Session of the Institution of Naval Architects April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

At a previous meeting of this Institution I had the honour to read a Paper treating of some practical points in marine engineering which were then comparatively new and untried. Although doctors still differ considerably about these and other matters, I have thought that it might not be uninteresting if I related briefly the results of a further experience of two years at Southampton upon the points in dispute, stating the conclusions to which I have myself been led, and inviting the opinions of other engineers.

I believe the question of surface-condensation must be admitted to be still, in some measure, upon its trial; the results obtained from it being frequently most perplexing and contradictory. I think, however, that it now begins to assume a more definite shape, and that it will be found that surface-condensation is either a great good or a positive evil, just in proportion as it is properly and judiciously carried out or not. That it can be made perfectly efficient, and a source of great economy of fuel, is sufficiently demonstrated by several of our large passenger steamers at Southampton; while, on the other hand, the most palpable evidence of its failure is shown by many boilers at that port, which have been utterly ruined and worn out, and in some cases renewed, after less than five years' work. What has been done in one case, however, may, of course, be done in others under similar conditions; but whether the conditions favourable to surface-condensation are such as can be universally applicable to the general run of sea-going steamers is, to my mind, very doubtful.

These favourable conditions I take to be the following:—The vessel should be a large

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foreign-going steamer, in which the cost of fuel is greatly enhanced by the distance it has to be carried, and in which, therefore, a certain saving in the consumption is of the highest importance. The vessel should have a staff of intelligent and well-instructed engineers—and this I believe to be, after all, the main element of success with surface-condensers. I may truly say, that I invariably find the successful application of this process associated with unusual care and intelligence in the chief engineer; and that corroded boilers, an imperfect vacuum, and a high rate of consumption are the characteristics of the normal "engine driver" of the old school, who can shew his certificate of twenty years' service, but nothing else. I am convinced, by ample experience, that the engineer of a modern steam ship is greatly benefited by a knowledge of the scientific principles involved in the working of his machines. His general intelligence is increased, he takes more interest in the duties of the engine room, and he acquires a power of adapting himself to circumstances, which is wanting to the uneducated man.

Another condition favourable to the development of surface-condensation appears to be, that the temperature and density of the steam shall have been previously lowered, by ample expansion in the cylinder, before it passes into the condenser. This state of things is generally found in foreign-going steamers, while it is wanting in the class of fast Channel packets, for example; and our experience at Southampton shews, that in such vessels, which are usually driven at full speed with high-pressed steam and but little expansion, there is no appreciable saving arising from this process. The steam, it appears, is not condensed with sufficient rapidity, the condenser becomes very hot, and the vacuum suffers. Probably an increased allowance of tube-surface for condensation would remedy the evil, but at a cost which it might not be considered desirable to incur. For in this class of vessel the most ordinary care will suffice to prevent an accumulation of scale in the boilers, (which is the principal reason for introducing surface-condensers) while the cost of the fuel is not so great as in foreign-going ships. For the large and increasing class of merchant screw steamers with auxiliary power, I think this principle should be adopted with great caution, as although, in some instances, it may be quite successful, in many others the boilers will be injured from want of the necessary knowledge on the part of the engineer.

That similar difficulties with surface-condensers are experienced in other countries, will be seen by the following extract from a letter which I had the pleasure to receive in the beginning of this year from the eminent and experienced French engineer, M. Lissignol, late Superintending Engineer to the Compagnie Générale Transatlantique. Referring to the former Paper which I had the honour of reading to this Society, M. Lissignol says (writing in English):—"The facts stated are of considerable character,

" and agree very much with the opinions I have always been advocating in my own " country. Practice has made me a sound enemy to all complications and *sophisticated* " *engines*, as you call them. The best things theoretically are useless when they are " placed in the hands of indolent and careless sea-engineers. I am nearly quite satisfied " of the failure of double-cylinders and surface-condensers, which have always given me " a great deal of trouble, and a considerable degree of annoyance, although I never chose " them myself, but was compelled to accept them—the shipowners being inveigled into " them by the inventors. The effect of surface-condensers is in fact very curious, and " I totally fail to explain the phenomena. It would be very useful if careful observations " were made by scientific men to discover the causes of the nuisance. I will try to " promote this in France. Is there anything doing for this purpose in England?"

I shall now state what, in my opinion, the proper management of boilers with surface-condensers ought to be. The boilers on starting should be filled up with clean sea water. The object of the engineer should now be to obtain as soon as possible a thin but uniform coating of hard scale over his boiler surfaces. With this end in view, he should work his boilers at first with salt water of a density somewhat greater than that of sea water—containing, say, one thirty-second and a half of salt; and he must at the same time stint his engines in tallow, and other lubricating material, which would otherwise find its way into the boiler, and prevent the scale from adhering to the plates. As soon as the surfaces are sufficiently protected, the density of the water may be diminished by admitting more feed from the condenser, and less from the sea; but the water must not be freshened much below the density of sea water, otherwise the scale will be dissolved off. The restriction of lubricating matter to the engines is essential both for the boilers and the condensers, the tubes of which are liable to become clogged with grease and dirt, and the vacuum thereby impaired, towards the end of a long run. The defect of vacuum caused by the heated water of the tropics appears to average from 2 to $2\frac{1}{2}$ inches of mercury. The water in the boilers should be entirely changed as often as practicable, since it appears to acquire an acid and corrosive property, either from decomposition of the tallow, or directly from the sulphuric acid with which tallow is usually purified. It is also very necessary that the water should be kept as clean as possible, to prevent priming.

Perhaps the most successful examples of surface-condensation at Southampton are afforded by the Royal Mail Company's large screw steamers, *Rhone* and *Douro*, each of 3,000 tons and 500 horse-power, which burn about 35 tons of coal per day, at an average speed of $10\frac{1}{2}$ to 11 knots. Having recently examined the boilers of these two vessels, I can testify that they shew not the least appearance of any undue corrosion going on, after having run some eighty thousand miles. Mr. Hugh Arthur, the intelligent

engineer of the *Douro*, has kindly furnished me with the following account of his treatment:—

"The pressure of steam in the *Douro* is 20 pounds. It is super-heated, and admitted "into the cylinder at about 304°. Expansion takes place in the cylinder for about two- "thirds of the stroke. The condensers are generally worked at a temperature of 118°, "when the vacuum is 26½ inches by the gauge, and 24½ inches by indicator card. "Within the tropics, with the sea at 82°, the condensers are worked at 126°, the gauge "shewing a vacuum of 25 inches, and the indicator 23 inches. The temperature of the "discharge water varies from 16° to 20° less than the temperature of the condensers.

"On the first voyage every precaution was taken to get sufficient scale over the "boilers to protect them, if possible, from the destructive effects so manifested in boilers "using surface-condensation. The density at which they were worked during this "voyage was one thirty-second and a half of salt. After running over 5,000 miles, an "opportunity offered for examining them, when everything was found to be going on "well, a thin scale having formed on the furnace tops and tubes. After another run of "over 5,000 miles with the water in the boiler at the same degree of saltness, it was "found that sufficient scale had formed to answer the required purpose, and the water "was then reduced to about the density of sea water, or one thirty-second of salt, at "which the boilers continue to be worked. Up to the present time there is little or no "alteration in them, for when the scale is found to increase or decrease, the density at "which the boilers are worked is altered accordingly. Every four hours a small quantity "of water is blown off through the brine-cocks, thus causing a gradual change of water, "which is found to be necessary. Also when arrived at any port, instead of letting off "the steam by the waste steam pipe (which only increases the density of the water), we "have them blown down and pumped up again with the donkey engine, which gives a "change of water without any extra cost. The only cleaning which the boilers require "is to sweep off a fine brown powder that gathers about the steam chests and up-takes, "these parts being afterwards coated with boiled oil between every voyage."

It should be stated that the *Rhone* and *Douro* have the great advantage of ample boiler-power, to which circumstance, as well as to the moderate speed at which they are driven (about 10½ knots), must in a great measure be attributed the remarkable economy they exhibit. As an extreme case on the other side, the *Normandy*, Channel packet between Southampton and Hâvre, burns 45 tons of coal per day of 24 hours, although she is only 425 tons burthen, with engines of 220 horse-power, fitted with surface-condensers; but then she is driven at from 13½ to 14 knots per hour.

The type of double or combined cylinder engines adopted in several of the large

steamers at Southampton continues to give rather unsatisfactory results. In the case of the *Mooltan*, the whole of the machinery has been removed, the engines being replaced by single-cylinder engines of a more simple construction. The boilers of this ship (using surface-condensation) have been entirely worn out with five years' service. The *Poonah* is likewise, I understand, to have new engines; her boilers are also much worn after four years' work.

I may remark here that the apparatus for super-heating the steam has been removed from all our Channel packets on the South Coast, and with apparent advantage. It was found to impede the rapid formation of steam, and to be troublesome and expensive from burning out so quickly. It is still believed to be of considerable benefit in the case of long-voyage steamers.

Steel shafts do not increase much in favour at this port. The objection urged against them is this, that when they break (and break they certainly do as well as other shafts) no warning is given, whereas a malleable iron shaft will almost always indicate its weakness, by shewing an incipient crack or flaw, in time to allow it to be removed before an actual rupture takes place. Nor do I think that steel plates, as hitherto made, can be regarded as being thoroughly trustworthy for the hull of an iron ship; for although steel may doubtless be manufactured of such a quality as to bend without breaking when the strain is applied gradually, it seems very doubtful whether it could resist a sudden sharp blow (such as would be caused by striking a rock or pier) so well as good malleable iron; at least we know that steel guns, even when made by Krupp, do not withstand the sudden concussion of the discharge, and that soft steel plates manufactured by the Elswick Iron Company, when given over to the tender mercies of the Iron Plate Committee, are starred with cracks by the first shot. I have recently examined two iron screw steamers running between Newhaven and Dieppe, in which the plates are so battered and punched by hard knocks against stone piers and loaded barges as to be indented quite half an inch between the frames, which stand out like so many hoops round the vessel, and yet the plates are not injured. Had these vessels been plated with steel, I question whether they would not have been knocked to pieces long since.

I am informed by the eminent French engineer already quoted (M. Lissignol), that in France it is quite understood that all shafts, whether locomotive or marine, may be expected to break after running from 150,000 to 200,000 kilomètres, however good they may have been at first; and that it is the practice of many companies to put aside and renew all shafts after running this distance, whether they break or not. The French kilomètre, I may observe, is less than the English knot in the proportion of 3,270 to 6,082 feet.

Much attention continues to be bestowed upon the very important question of the fouling of iron ships, and I need scarcely say, that any one who is interested in the docking of vessels at Southampton, has an excellent opportunity for comparing the results achieved by the various compositions employed to prevent fouling. Most of the anti-fouling compositions which have been patented, contain, as one of their principal ingredients, a poisonous salt of some metal, generally copper, mercury, or arsenic, which is intended to prevent the growth of algæ and shell fish. Such, however, is by no means the usual result, since both grass and barnacles absolutely refuse to be poisoned in this way, and are found attaching themselves to the most pernicious compounds in defiance of chemists and inventors. Were this the only demerit of these so-called anti-fouling compositions they would then be no worse than red lead, or other innocent pigment, but in reality, they have far more serious sins to answer for. It is found in practice that most metallic salts, but more especially those of copper (such as the oxide and sulphate of that metal) are subject to decomposition by the sea water, metallic copper being deposited. This copper is innocuous only so long as the surface of the iron is perfectly protected by its usual coating of red lead, for should the paint get rubbed off at any point, either by the anchor and chain cables, or the unavoidable abrasion of fenders and boats, the copper then becomes highly dangerous to the iron plates of the vessel, in consequence of the galvanic action which is immediately set up. Yet such is the irrepressible nature of inventive genius, that these metallic compounds are still being constantly re-invented and applied, only to be rejected after they have done their destructive work upon the bottom of some unfortunate ship.

Our great Steam-ship Companies at Southampton appear now, after innumerable trials, to have unanimously adopted a composition which works upon a principle differing from that already referred to; that is to say, it does not take any strong measures with the barnacles, but simply declines their proffered attachment by presenting to them a slippery and slightly solvent surface, like the back of a porpoise. As this particular composition (known as Peacock and Buchan's) does not contain any metallic salt capable of decomposition by sea water, galvanic action cannot be induced; and it certainly appears to have no more effect upon the iron plates than the red lead over which it is payed; while, by its slippery and mucous nature, it probably assists the passage of the ship through the water. By applying this composition at intervals of from four to six months over two coats of red lead paint, our iron ships at Southampton are kept practically clean and free from oxidation.

DISCUSSION.

Mr. George Barber (Surveyor to the Board of Trade): With regard, Sir, to what Mr. Murray has said about steel, it may, perhaps, be interesting to the Institution, if I give them the results of some recent examinations I have myself made of steel-built ships. I quite agree with Mr. Murray, that the great difficulty that has to be overcome, is the want of uniformity of character in a number or parcel of plates supplied for steel ships. Although we may find plates that may be bent and twisted and worked into any shape without injury, it is quite probable that other plates, delivered in the same parcel, may be quite unfit for use, and should not be used in the construction of a ship. What we need most just now, is, that the manufacturers of steel should devote their attention to giving us some good metal—call it mild steel, or whatever name you please, upon which shipbuilders may rely with as much certainty as they now do upon iron. It may, perhaps, be interesting to the Institution, if I tell them that I was in Ireland in the early part of this week, and that a very important, interesting, and instructive trial was then going on in the Civil Court at the Antrim Assizes, a report of which has reached me this evening, and which I shall be most happy to place in the hands of any member who may wish it. The trial occupies several columns in the newspaper. It was an action brought by some eminent shipbuilders at Belfast against some steel manufacturers of Sheffield. They were building some ships 400 feet in length, and the shear strakes were required to be doubled. It was thought that weight would be saved and strength obtained by adopting steel instead of iron. Steel plates were ordered, and I find that the makers guaranteed a supply of plates which should bend double cold, and be fit for shipbuilding purposes. The most extraordinary part of the case is, that the plates were worked on the vessel's side, and two or three days after they had been put in their place, they cracked suddenly, and the cracks were so bad that surveyors were sent from Liverpool and other places, and the whole of the steel plates had to be taken off, and Low Moor plates substituted. The trial is most instructive, and there are some very extraordinary statements made, both by the makers of steel, and by shipbuilders. One statement, which I think it is very important for an Institution like this to know, made by the makers of steel is, that steel is at present on its trial, so far as shipbuilding is concerned. Another statement is, that steel cannot be made $\frac{5}{8}$ thick reliable for ship building. This, mind, is the statement of the makers of steel, and it is well that the Institution of Naval Architects—now that steel is so much thought of, and that the advantages of the use of steel, if it could be got of a reliable character, are believed to be so great—should know these facts. Some of the most successful steel ships which have been built, have been built by a member of this Institution,—Mr. Wigram. They have come under my supervision, and one of them will be known to you all as having been in collision last year with a barque in the Channel, when some persons lost their lives. I allude to the *Samphire*. I examined that vessel just after the collision, and nothing could exceed the excellent character of the material and the excellence of the workmanship. But Mr. Wigram himself in writing to me (and I am sure he will excuse me for quoting part of his letter, knowing that it will be of great value to the Members), says:—"The great difficulty up to the present time has been in the manufacture of plates of "sufficient strength and thickness for sea-going vessels; in fact, when we last enquired about it, none "of the makers would guarantee anything over $\frac{3}{8}$, and this was of an inferior quality to the $\frac{1}{4}$, so that "at that time there was no implicit reliance to be placed on any steel. When we built the *Samphire*, "the *Breeze*, the *Wave* and other vessels, we had to condemn many plates for brittleness, though others

" in the same parcel were all that could be wished." That shewed that the difficulty to be overcome, is to get a uniformity of character in the material. I was at a building yard last Saturday, where a steel ship was in frame, and some of the frames were shown me. One of the angle steel frames was put under the shears in my presence, and fell in three pieces like a piece of crockery ware. I saw some of the plating myself. When the plates were put on, and the riveters commenced their work, the edges of the plate broke away between the rivets and the plating had to be taken off; the reverse frames had been riveted before the plating was put on, and when the riveting commenced, some of the frames cracked, and they also had to be removed. It is a most important matter, and if there should be any manufacturers of steel present, I hope they will not take offence at the remarks I have made, but will devote their attention to giving us something which will be so reliable that we can unhesitatingly employ it; and the advantages that will follow both to shipbuilders and shipowners will be very great.

Mr. ROCHUSSEN: Although not one of the steel manufacturers of this country, I cannot help rising to protest most strongly against the assertions made by the author of the Paper, and also by the gentleman who has followed. In the first instance, steel shafts are not unreliable; they are only unreliable when they are made on wrong principles, or invoiced under false pretences. Steel shafts when made of puddled steel, which in itself is an admirable material for tires or plates, from the moment they are put into those heavy blooms which are requisite for shafts or cranks, do not have that opportunity for solidly forming in that homogeneous mass which we reach by the only material fit for our purpose, namely, crucible cast steel. If, in a puddled steel shaft, when it is finished, we have reached perfect homogeneity it may also follow that by the frequent re-heating which it has required in order to become a perfectly weldable mass, it has been reduced to iron, and if the engineer who specified that shaft to be made of puddled steel has also reduced the seantling which he would allow, from iron to steel, it is the engineer who is responsible for want of strength, and not the manufacturer; the manufacturer is responsible only to this extent, that he has simply followed instructions which are impossible to reach. If, on the other hand, the steel shaft should on trial be found to be the puddled steel to which I am alluding, it would shew that as such it was an imperfectly weldable mass, and therefore morally unreliable on that score. If a shaft made on that principle is sound it is iron; if it is steel it has all the elements of weakness from not being properly prepared. The same remark will also apply to steel shafts made of Bessemer steel; I have the highest admiration for the conversion of iron into steel by the Bessemer process: I myself work it on a scale of some magnitude, but I should be the last to put it in forgings of great size. Whenever we attempt to weld it together in larger masses than from 7 to 10 ewt. we fail, and we fail also in forgings, because the crystallisation of the material is so close that in re-heating it for every subsequent forging, the proper heat to reach the core in annealing it will be sufficient to de-carbonize the whole of its skin, and turn it into iron again. Now, Sir, with regard to steel plates; there, again, it is really a matter of misery almost, that engineers do not consult with manufacturers as to what they can do, and what is impossible. Very often certain ultra-ambitious specifications are made. I myself have had a great deal to do with them, and have refused them, and modified them. Engineers boldly state " I want in the frame of my " ship, or in this bridge, steel equal to 48 tons per square inch, or 42 tons per square inch, and so on, and " I want it to elongate well, and to weld well, and so on," and in reality they have thrown the blame of failure upon their own profession, because the thing is impossible. Steel which will work well, which will equal iron in all its virtues, and which will excel it in its working strength, cannot be made beyond 34 or 35 tons per square inch. If you want to have steel simply to punch, or to resist pressure,

by all means make it up to 70, 80, and I believe even 100 tons are not impossible, but if you are to put it in the hull of a ship which has to be twisted, and then recover again its original shape, you must have elasticity; you must have the power to yield, and to elongate. Well, in good steel we can give you a power of elongation to the extent of from 15 to 20 per cent., and we can give you the power of contraction to the extent of from 12 to 14 per cent.; but the moment you begin to reduce the weight of the ship to about one-third, or even more than that, and endeavour to substitute a material which is really altogether fabulous, you introduce the elements of failure. So, again, passing from ship's hulls to ship's boilers:—attempts have been made to introduce cheap steel for boilers, and this cheap steel has been of the puddled steel class. Now puddled steel is, perhaps, the finest material for every work of construction in a cold form; it is far superior to cast steel for the skin or frame of a ship, but the moment you put it into a boiler you have again the elements of a particular failure, and this for a reason which is not apparent to many engineers, and which is most likely known to steel manufacturers only. It is this, that puddled steel contains a large quantity of free carbonic oxide, and that carbonic oxide if put in contact with heat will draw bladders, and in nine cases out of ten steel boilers made experimentally ten and twelve years ago, here and abroad, have blistered, and, so to say, pulled themselves asunder; and there, again, was the mistake of the engineer not consulting with the man who made the material. A third source of weakness in steel frames, which the last speaker casually alluded to, is to be found in the rivets. The rivets are sometimes apt to snap their heads, and sometimes they tear the plate asunder. Well now, that again is the fault of the constructor in using steel rivets carelessly made. The steel in the round bar is, as a rule, put under a certain punch; by certain very clever machines the rivets get squeezed into a certain form, they are then passed into store, and as they are wanted they are simply heated, and that steel is then put between two pieces of cold iron. Now, Sir, in dealing with a steel rivet, which after all is a small forging, we should never attempt to subject it to heat, unless that heat be gradually cooled down, unless by annealing we allow the difference in the form of the steel to take place. I am only saying this because I am using steel rivets myself. In our own constructions, for our own purposes, we should never think of using a steel rivet unless, after it has been made, it has been put through a thoroughly good annealing and a very quiet cooling down. It was my intention to have read a Paper on this subject at this Meeting, at least during this Session, only I thought the matter was so inferior to the general mass of information that it would be simply taking up the time of an important body of men for a very small purpose. Not many days ago I went to one of our annealing furnaces where steel rivets were being annealed. We generally put ten thousand of them into one charge, this charge taking twenty-four hours in heating, twenty-four hours in the fire, and three times twenty-four hours cooling down, so as to allow the material to settle itself. I found that in eight rivets out of every hundred after they came from the annealing furnace, the heads had been worked and twisted into almost every conceivable shape. One was slanting at an angle of 10 degrees, and another at 20 degrees; some had swollen to the shape of a mushroom, while others had taken the familiar form of a champagne bottle, simply showing that the rivet whilst being heated and pressed had been forced into a particular form which nature did not intend to assign to the steel. If we had taken a steel rivet which after punching was not annealed, and simply made it hot and put it between two cold iron plates, we should have had there a material a great proportion of which ought to break, and was never intended to stand. Therefore, in this way, even in rivets, you get elements of weakness. I have simply risen to vindicate, more or less, this fact, that it is folly on the part of engineers when dealing with a material which, in this country more

than any other is not well understood, to give out specifications intended to answer a certain purpose, unless they are willing to go hand in hand with the makers of the material.

Mr. SAXBY: I think the question of iron is so fully before us, that I may be excused if I ask Mr. Murray a question, namely—what he considers to be a test of the goodness of iron—what he considers to be good iron?

Mr. MURRAY: It depends, of course, entirely upon the use to which the iron is to be applied. For shipbuilding purposes, of course, iron must have many qualities which would be unnecessary for other purposes.

Mr. SAXBY: May we, as a general rule, consider that that iron is good, which bears a good tensile strain? Mention has been made of steel being required to bear tensile strain—40 tons a square inch.

Mr. MURRAY: That would not be good iron for shipbuilding under all circumstances. It must have many other qualities.

Mr. SAXBY: Having asked you the question, will it be in accordance with your opinion, if I assume that good iron for general manufacturing purposes is that which can be tied cold into an overhand knot?

Mr. MURRAY: Yes, I should say so, certainly, decidedly.

Mr. SAXBY: My reason for asking is simply this—that if you will allow that good iron for manufacturing purposes is that which can be tied cold in an overhand knot, I am in a position to declare, from recent experiments that have been conducted by me at Sheerness, but which are not generally understood, that by means of magnetism, considering the magnetic condition of iron, I can test the qualities of iron, and I can also test its condition, its faults and its fractures, in manufactured articles. I am not aware that that has yet been done by others. I am aware that persons place themselves in a very awkward position, when they assume to do what others cannot do, but I am constrained on this occasion to put forward a few remarks depending upon some experiments, which have extended now over about four months. I find great difficulty in getting manufacturers and others to believe that I can do what I assert that I can do, and I shall be very glad to shew any one here, this evening, what I really can do in the way of testing iron. I think it bears so strongly on what has been said, that I am quite justified in bringing the matter forward. I have here two iron bars covered with cloth. No one in this room can see the quality of the iron. Bars have been brought to me in this condition—bars of different lengths—some of them 5 or 6 feet long, and some plates of iron have been brought to me, and I have been required to prove that I could tell the quality of the iron, and to detect any faults. Now, if there is any gentleman in this room, who, without seeing these two bars, covered as they are in cloth, can tell me which is good iron and which is bad iron, which contains faults and which does not, I have no occasion to say anything more upon this subject; but, if there is no one else present who can do this, I beg leave to say, respectfully, that I can do it, and that I am ready to shew in what manner.

The CHAIRMAN: I have no doubt that before the Meeting is over, some one will tell you that he can do it.

Mr. BOURNE: The question of iron and steel, though certainly referred to in Mr. Murray's Paper, yet I think occupied but a very small portion of it; and therefore, perhaps you will permit me to recal your attention to the subject upon which Mr. Murray touched first, namely, surface condensation. Now,

I quite agree with Mr. Murray in thinking that, for all moderate pressures of steam, such as 25 lbs., surface condensation is not required. But surface condensation forms a part of a larger question, and its main advantage is that it enables us to introduce steam of a high pressure. We cannot introduce high pressure without the use of surface condensation. If we go to a pressure beyond 40 lbs. we know that sea water deposits sulphate of lime, not by concentration, but from the mere fact of its increased temperature; and if sulphate of lime, or any other salt, is deposited on the surface of the iron, the boiler cannot be safe, but it will be very liable to burst. For this reason, surface condensation is indispensable to a high pressure of steam, and a high pressure of steam is indispensable to the large employment of the principle of expansion, whereby alone we are enabled to work with great economy of fuel. Therefore, Sir, I think it is important that we should see that the question of surface condensation is one that should not be considered by itself, but that it is part of a larger question, and should be discussed with reference to high pressures of steam, for it is only when steam of a high pressure is used, that any advantage is got from surface condensation. With respect to double-cylinder engines, I think, whether we have a double-cylinder engine or a single-cylinder engine, is quite immaterial. The whole question is one of expansion. We can have a certain expansion in one cylinder; we can have an equal expansion in two. One cylinder is quite as effective as two, and I agree with Mr. Murray in thinking that one is better than two—that double cylinders are unnecessary unless we go to very high pressures. With regard to super-heating, which has also been referred to, it is quite well known that super-heating does corrode the inside of a boiler, or of a super-heating vessel of any kind. In fact, if we raise the temperature very much a super-heater becomes a machine for the production of hydrogen gas. We all know the familiar experiment of generating hydrogen gas, by sending steam through a red-hot tube containing iron turnings. The oxygen unites with the iron, and the hydrogen is liberated. Now, the superheater acts in a similar way; but I think it would be quite possible to prevent that corrosive action if carbon were introduced in some way into it, because oxygen has a greater affinity for carbon than it has for iron, and if carbon were introduced in some way or other—perhaps in the form of coal tar, or pieces of charcoal hung in an iron cage, or something of that kind—it is probable that the corrosion of the superheater would be prevented. With respect to improvements in steam navigation, I am sorry to have to say that there have been none within my recollection. We have boilers and furnaces much the same as we have always had, fired by firemen of whom it is necessary in large vessels to have a large number. I think that with so many ingenious men directing their attention to that subject, we certainly ought to have something very much better than this now-a-days. I believe that before many years elapse, we shall have gas furnaces, and that the fires will be done away with. Already gas furnaces are introduced in iron making and many other branches of manufacture. Why they should not be introduced into steamers I do not see; and by that arrangement you will get rid of the firemen, and will get a better performance, because it is very difficult indeed to get a good performance from coal as it is now used. If this arrangement were carried out, I think we should have something worth calling improvement to chronicle. At present, I think we have not any.

Mr. GALLOWAY: If there has been no practical improvement in connection with the steam engine during the experience of the gentleman who has just spoken, it has not been the fault of inventors. Samuel Hall was the inventor of surface condensation; Samuel Hall endeavoured in vain, for years, to get that which has been eulogised this night by gentlemen in Her Majesty's service introduced into the Navy. Samuel Hall died a poor dependent man, to the disgrace of the age in which he lived. The fault of

the age is not that we want inventions—not that they cannot be produced; for, I will assert, as one of the despised and neglected class of inventors, that there does not exist a necessity, mechanical or otherwise, within the range of possibility, but there is intellect to meet it in this, our day—but the fault lies in the age in which we live. In one word, it comes to this, that neglect has its consequent punishment. We are not alone the sufferers—the age in which we live suffers correspondingly with us. But this is the meaning of the whole, surface condensation means better dividends for shareholders and steamship promoters; surface condensation properly applied means not only the saving of fuel and labour, the lives of our stokers and enginemen, who are kept down in places too hot by far for any men to endure, but it means also a great saving of the national expenditure and the advancement of the glory of our country.

Mr. Scott (of Greenock): I think we have been a little apt to wander in the course of our discussion upon this interesting Paper, which Mr. Murray has introduced. If you will allow me, I will say two or three words in reference to the remark of Mr. Bourne, that surface condensation should not be taken directly as a means of economy, but as the means of obtaining a higher pressure of steam at sea. I think Mr. Murray said in his Paper, that, during the two years that had elapsed since reading his former Paper, no increase of pressure had taken place in the steamers working from the port of Southampton; but, although that has been the case there, yet in other parts of the kingdom, a very material advancement has been made in this direction. From the port of Liverpool there are now, I believe, at least twelve or fifteen steamers working regularly at sea, with 60 pounds pressure—using, of course, surface condensation as a means of obtaining that, and certainly with a very notable economy. I have constructed several of these steamers myself, and am consequently familiar with their performances. I believe that by the use of this high-pressure steam they have been enabled to perform voyages, which, as a matter of regular communication, have been hitherto unattempted,—I refer to the voyages which have been made by some of these steamers from Liverpool to China and back, only taking in coal at two stations. I think Mr. Bourne, himself, very many years ago, laboured in that same direction. Whether this system can be continued as a commercial speculation depends, of course, very much upon points which are entirely apart from mechanical ones; but a sufficient number of voyages have already been made, to prove that in a mechanical point of view, the operation can be conducted. I certainly think that by employing steam at high pressure, ocean navigation may be extended very much more to the advantage of the country than it is now. The difficulties of employing high-pressure steam are, on board steamers, not a few; but I think that those difficulties, which Mr. Murray has alluded to in his Paper, as causing the removal of complicated machinery, and the other disadvantages to which he has referred in his Paper, may be overcome by attention on the part of engineers, to the attainment of simplicity and fewness of working parts,—the absence of which, I rather fancy, is that which has caused the condemnation of the vessels to which Mr. Murray refers. I believe that if marine engineers were to look more in that direction, they would do so with advantage to their profession. I would certainly recommend that improvements in marine engineering should take very much that form.

Mr. Robert Murray: I have not much to say in reply, except to mention that the steel shafts to which I alluded as having been broken were Krupp's shafts, and that they were made of the same size as wrought-iron shafts would have been made. They were of the same dimensions exactly, and they have broken in several instances to my certain knowledge.

Mr. Rochussen: Do not mention names, unless you know inherent faults of manufacture.

Mr. MURRAY: My Paper is a practical Paper. I do not theorise upon subjects, nor go into the question of the manufacture of steel; I only state what has come under my own observation, although it seems to me that steel requires so much humouring and coaxing that it must be always a very doubtful material for shipbuilding purposes. We can never be certain of getting the exact quality of material that we require for a particular purpose. As to surface condensation, I quite admit what Mr. Bourne says, that it is of most advantage if high pressure is employed. At Southampton, practically, we have no vessel using higher steam than perhaps 30 pounds. We are not so go-ahead there as they are at Liverpool. I know, and I am quite sure, that in vessels using 50 or 60 pounds pressure, surface condensation would be of much more importance and advantage than it would be in any other case. As to general improvement in steam navigation, I really do not know that we have advanced very much within the period of the last ten or twelve years. I think the old-fashioned principles of large boiler power—well-proportioned boilers, careful management, simple machinery, a considerable degree of expansion in one cylinder, and steam of moderate pressure—at least up to about 25 pounds or 30 pounds to the inch—are still the elements of our best practice at the present day.

The CHAIRMAN: I am sure we must all thank Mr. Murray for his Paper, and for the discussion that has occurred upon it. It has rather run beyond the limit of the time, and therefore I will make no further remarks.

ON AN IMPROVED METHOD OF CONSTRUCTING COMPOSITE SHIPS.*

(*Second Memoir.*)

By Michael Scott, Esq., C.E., Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

The drawings (shown in Plate VI.) represent part of the side of a ship built according to the author's plan.

The frames are of T iron, instead of angle iron, all fore and aft the ship, and, being stronger, they are spaced further apart.

Betwixt the frames are fitted chocks of teak bolted to the frames with iron bolts, and caulked throughout—forming, in fact, a water-tight ship.

Over these chocks and over the frames is wrought the outside planking, which is fastened, as shown in the drawings, by brass bolts, which pass through the chocks and planking, and which may be either clenched or screwed with nuts.

It will be observed that the planking overlaps the seams of the chocks, so that there are no through seams.

With existing appliances, the frames fore and aft will be somewhat more difficult to set to the figure of the ship than frames of angle iron; but, on the other hand, the number of frames to be so set is less than in the ordinary method of building composite ships.

Thus in a vessel 200 feet long, the number of frames would be fewer by at least twenty. Fig. 4 shews the construction in an extreme case.

The prominent advantages of the author's arrangement are the following:—

1. The framework of the ship, with the same quantity of iron, is considerably stronger than with the ordinary construction; or the weight of iron may be reduced, and the framework remain as strong.

* Received April 12th, 1867.

2. The yellow-metal bolts are entirely removed out of contact with the iron, thereby preventing the risk of galvanic action.

3. The attachment of the timber planking to the framework is much more thorough than in other methods, and adds more to the strength of the ship. In the ordinary construction, the timber hangs upon the bolts, whereas in the improved method the timber embraces, and is supported by the frames.

4. The ship will be much more rigid than those constructed in the ordinary manner, and less dependent upon the usual means employed for stiffening the hull.

It has been said that the frames are more difficult to set; but if the system be adopted, this, like difficulties common to new constructions, will no doubt be overcome, and the saving in the number of frames will go to compensate for the extra cost of setting.

More labour will be required to fit the chocks; but, on the other hand, the timber in these chocks will cost one-third less than the timber in planking, and the expense will be further reduced by employing a shaping machine.

For the purposes of comparison, Figs. 5 to 8 are added, shewing some other methods of constructing composite ships.

Comparing the arrangement shown in Figs. 5 and 6 with the author's plan, it appears that it is inferior in the following particulars:—

(*a*) The total weight of metal in the frames being the same, they are not so strong.

(*b*.) The frames are more weakened by bolt holes.

(*c*.) The attachment of the timber planking to the iron frame is not so thorough: the timber hangs upon the bolts.

(*d*.) The fastening of the butts of the planking is more expensive,—a matter of some importance when it is considered that there may be 400 or 500 such fastenings in a ship. Further, the bolts are in lines along the edges of the planks, which is not so good a fastening as when they alternate.

(*e*.) The ship would be deficient in rigidity, and therefore would require diagonals.

(*f*.) All the seams are through seams, and require extraordinary care in caulking.

(*g*.) Screw bolts must be used, as clenched bolts are not applicable.

(*h*.) The brass bolts are in direct contact with the frames.

Turning to the method of building shown in Figs. 7 and 8, the foregoing observations marked respectively (*a*), (*b*), (*c*) and (*e*) appear to be applicable to it; and if the bolts fastening the inner skin to the frames be brass, the objection (*h*) would also apply.

If these bolts be made iron, then they would be nearer the copper sheathing and water than in the author's plan.

The author's system of construction will have the highest grade assigned to it at Lloyd's.

Two important points remain to be noticed—*viz.*, weight and cost.

With regard to the first, weight: the timber in the author's method will weigh more.

The bolts will weigh less than in Figs. 5 and 6, and considerably less than in Figs. 7 and 8. There are no butt plates, and the weight of these is therefore saved. The result is that, assuming the iron structure of the ship to be the same, the total weight of hull would be very nearly the same in the three arrangements shown.

But inasmuch as it is believed that, for a given strength, the weight of the iron structure in the author's method might be reduced, it will follow that his plan will weigh less than the others.

With respect to the cost: an experienced builder carefully examined the construction, and even assuming that the iron structure was made of the same weight, he offered to build at a very small advance upon the price for composite ships of the cheaper kind.

DISCUSSION.

Mr. Bettely: The plan which Mr. Scott has shown to-night is very similar in its character to one brought forward by Mr. Jordan two years back. Now, it is well known that in a wood-planked ship the frames are required to be of very great strength, because it depends upon them whether the planks are kept in place. In an iron vessel it is the reverse; the plates being riveted together, the frame then becomes comparatively useless; so much so, that you could build an iron ship without a frame by making the plates thicker. But when we come to this plan of introducing an iron frame, which in an iron vessel is merely a slight stiffening of the various parts—introducing that light frame, where it has to do a strong work,—I say that it is one of the greatest defects that can be found in composite ships, because my experience for a number of years has been this,—that such vessels have been built, and they have looked good and strong, and they have gone to sea; and when they have been at sea for a little time, after rolling and going through heavy weather, they have leaked; the vessels have got safe through their voyages by pumping; they have been put upon the slip, or graving dock, and it has been a difficult thing to find out the leak; they have looked excellent, and everything has been tight. The fact was that all the parts, which had opened at sea, had gone together again. Now, that shows to me clearly that a composite ship depends for

its strength upon its frame; and unless you adopt some peculiar form of frame, such as will give strength equal to the ordinary frame, the composite ship is not perfect in the present day. With regard to the plan shown here, I must say that the last one introduced by Mr. Scott is an improvement upon the first, because he has added a little more material. But although he has added a little more material, he has altered the mode of fastening the frame to the planking. You can always fasten a light article to a strong one. For instance, I could put a piece of paper against that wall; but I could not put the wall against the piece of paper. Now, here we have a strong wall—a thick plank—set against a strip of paper; that is the likeness of it. In the former plan, you find that the bolt passes through a piece of iron nearly half an inch thick; the bolt is attached to the frame through the planking; and the leverage then becomes so great that there is a tendency to work, on account of the small quantity of iron. Now, in this latter plan he tries to prevent that defect by making a complex, or a compound, or a composite—it is a double composite, this. It has got an internal something or other; but what it may be I cannot tell. Some pieces are stuck in between the frame, and he is going to attach the planking to that. Now, that seems to me a very loose way of working. I think it would require a cabinet maker to make that; it does not look much like shipbuilding work. If you will allow me, I will show you a plan upon which I think a ship ought to be built. This is the frame described by Mr. Scott (pointing to the diagram). Here he has a flange of the iron, reducing the strength. He says, "Well, I must have that, because I want to get "something to fasten the ceiling to;" and he attaches an inner bit of planking, and rivets it on to this. Now, we all know that the strength of iron, when it is put in right lines, is as the square of its depth. When you destroy the iron, you are going to work upon a system in which this calculation cannot be carried out, because, although this flange—the outer flange—gets strength, still, when you take into consideration all the loss that you sustain by boring those holes, the addition becomes useless. Now, as this piece of iron is proposed to be fastened, these right lines, upon which you depend for strength, are lost; but Mr. Scott proposes to overcome that by attaching another bolt, but there is this objection, that whenever you bore a big hole in a piece of iron the strength is diminished, and I consider that to be a defect. The next defect in this description of ship is this:—iron attached to iron, according to my experience, does not corrode so much as when iron is applied to wood; the corrosion goes on much quicker in the latter case; and the consequence is that this must be taken into consideration when you are about to build a ship which is supposed to be classed for fourteen years. Therefore, I consider that the present form of iron frames, which has been proposed by Mr. Scott, and which has been used for iron ships, is unsuitable for composite ships. What I would propose is this. I would make an iron frame of ⊔ section iron. Thus I can dispense with the reverse angle iron, and the ribs are kept perfect without the punching of holes, this double-ribbed iron frame being to take the place of the ordinary oak of wood ships. I make it of such a size as to be equal thereto. Between the flanges or double ribs of this frame (at parts) I fill up with teak, for the purpose of receiving the ceiling thereon. The outside planking is laid on at the back of the frame and fastened by screw bolts and nuts to the iron frame. The ceiling is fastened by passing bolts through and through, that is, through frame and outside planking, thus giving increased strength in fastening over any mode of application of reverse angle iron with its rivets, or of any composite ship that has ever been built; it has simplicity for its construction and combination for its strength. Now, seeing that this ⊔ section of iron for torsion or other strains is stronger than this ⌊ section of iron, I think it is worth the consideration of this Society whether such a description of iron should not be adopted as most suitable for building composite ships. When building such ships I would begin with a

wood keel, and place my strong wood floors over it in the ordinary manner, and bring down the double-ribbed iron frame, as shown, over or on the top of them. The advantage of this is that, the floors of the ship, being constantly surrounded by bilge-water, are not so liable to be destroyed as the thin iron floors in a composite ship. A vessel of this description, of 10 or 12 years class, was recently surveyed in Liverpool, and all the iron floors were found to be destroyed by the action of the acid in the bilge-water; therefore I think it is of importance that in building composite ships wood floors should have the first consideration, for by this means you give great strength and durability. Such vessels will require little ballast, as the weight of the ship will be in the bottom. Mr. Scott has rightly said that, as to making calculations of quantities, it is not so much a question of quantity as of whether the work can be done. A few tons of iron in a ship are of very little importance; 10 or 20 tons of iron in a 1,000-ton ship ought not to be a consideration. The question is whether you can build a cheap and good ship; I believe that any good mechanic or shipwright can build a good ship if you will only give him money enough. It is only a question of money; but my object is to build the cheapest ship in the world, and the best, and to do that I must build the simplest ship. If I build a ship of this description, instead of beginning with my iron keel and my iron floors, I commence with an ordinary wood floor, and I bring down the frames on the top of it. The advantage of that is, that iron floors being continually surrounded by bilge-water are very liable to rust and decay away; in fact, it has been proved. A composite ship of ten or twelve years was examined (as I have already said) in Liverpool, and the iron had all rotted; therefore I think that that is important, and that it should be taken into consideration when building composite ships. I believe the timber had a great deal to do with it. It is, as I remarked, many iron ships are perfectly dry; but in composite ships, when you have to depend upon the caulking, they are very liable to leak, and that acts upon the iron, and destroys the whole of the iron. I think, therefore, that it is a necessity, when building composite ships, that you should have wooden floors. Then, again, by having this iron pass over the top of the floor, you may fill it up with cement, or teak, or anything of that sort, and preserve it from any accident. Beyond that, there would be another difficulty about coppering composite ships. I have, within the last three or four years, paid a great deal of attention to that; and I believe I have succeeded in showing that you can cover an iron vessel, or an iron-plated vessel, with copper sheathing, just as easily as you can wood. About three years ago, I made some plates for the Government, and put them on one side of the *Caledonia*. These plates were formed of copper on one side, and of white metal on the other. The copper had no action at all on the white metal; and the white metal, going over the iron fastenings, placed there as copper sheathing, after having been on three years, was taken off two months ago, and it is as perfect now as it was the first day it was put on; and the iron fastenings underneath are perfect. Therefore, I do not think we need complicate the question when we can effect the object in such a simple way. All my endeavour is that we should build the cheapest ships, and the best ships; mark you, I do not say cheap and nasty ships; but when you come near to simplicity you come near to perfection. Whenever you go away to complex, compound, composite ships, I think you are going wrong.

Captain HENDERSON: About 20 years ago, I designed a compound ship. I think it was in the year 1850 that I brought the matter before the Board of Trade, and I quite agree with some of my friend's remarks, as to the great care required. Some years before that I had built an iron vessel. I may say that I have been 50 years a sailor, 33 years a shipbuilder, and a quarter of a century an engineer, so that I combine, as far as practicable, the whole three; and this vessel, the *Assam* steamer, was the result

of those three things. She was 450 tons. I built her in 1839, and I found there, as I had to be shipbuilder and all myself, that there was some difficulty in taking care that the lines on which the vessel was built should be correct. I put the diagonals or riband lines of angle iron inside the ship instead of outside, and kept them on, and sent them out with the ship. I added wood planking between them, and this is a good vessel now, though eight-and-twenty years old, and in 1865 was lengthened as a barque. About 1845, I designed, as a mail packet and opium clipper, a vessel of 360 tons, of iron frames with timber planking. The object was that the entire outside keel planking should be wood, and the inside frames and beam of iron. The plan was very simple. It was that all the diagonals inside be screwed to the frames, and those diagonals to go the full length, so that the vessel's frame and beams should stand without a bit of planking. To that I added a thick keel and planking of teak, and adopted the system of galvanized bolts. In India they have a plan of putting a mixture of pitch and quicklime upon the top of the bolts, which allows you to copper perfectly, and nearly all our old Chinese ships had copper bottoms, and this *serangustee*, as it is called, answers perfectly. It is a peculiar mixture. It is put on pretty thick, and will last as long as the copper lasts. This vessel, besides having all the bolts galvanized, had screw bolts inside, and the heads allowed to go half an inch in, so that you could copper upon this iron ship as well as upon any other. It was only a different mode of doing the work. It answers very well in Indian vessels. I am confident that vessels could be built upon this principle, and I brought it before the Board of Trade. The principle was that the whole of the outside was timber, and the whole of the inside iron, but the two were so distinct that even before the planking was put on, or even the keel, the iron frame was strong enough. This saved about 40 tons, leaving all the strength of the iron. There was no part of the iron but what was actually in contact with the planking. There are drawings of it. There must be some in this Institution. However, I brought it before the Board of Trade, and they will be found there. I am quite certain that this is the system for the general trade of India. All these composite ships ought I think, if possible, to be made of teak. I am sure that this is of great importance in the building of iron ships. I am also sure that great advantage is to be got by combining wood with iron.

Mr. W. C. Miller: When composite ships were first constructed I took a deep interest in them. I quite agree that the first composite ships that were ever constructed had in them elements of failure in connection with the fastenings, and the consequence was that leakage ensued. But, by referring to the plans of Mr. Scott, it strikes me that he has got rid of that difficulty altogether by tapping the frames and screwing the bolts in. Mr. Bettely, in condemning the present system of fastening by screw bolts and nuts, applies the same mode of fastening in his extraordinary method of framing by punching the hole in the frame sufficiently large for the bolt to pass through without injuring the thread. I cannot understand how Mr. Bettely will overcome his objections to the system of planking on the composite principle, when at the same time his system of planking has the same deleterious effect on the iron frames. I have no doubt myself, Sir, that building composite ships will by-and-by be the rule and not the exception. I am free to confess that when Mr. Jordan built the *Marion Macintyre*—the first that was built—I myself, as a shipbuilder, had strong objections to it, from the fact that the system of fastening was anything but correct; but since then improvements have taken place in the building of composite ships, and those objections which were made to them by shipbuilders previously have been overcome, and I have no doubt that we shall have our mercantile ships built on this principle.

Mr. BARNES: I should like to say a word or two upon Mr. Scott's Paper, which is a very valuable one, and we ought to be obliged to him for having shown us what he proposes to do, and how he proposes to build his composite ships. There are one or two elements in his system which I should object to. The inner skin being in short pieces does not contribute, I think, anything to the strength of the hull structurally; therefore I think in that point it is objectionable. In the second place, I think as he gets to the extremities with the T iron frames, he would find the bending of them rather a tough job. These are the only two points, I think, which I have to notice. I think Mr. Miller must have misunderstood Mr. Scott when he stated that he proposes to tap the frames. I certainly never heard of Mr. Scott's frames being tapped before, although I carefully inspected his drawings only a few days ago. Tapping the frames has been proposed lately, and the plan originated in the office of the Controller of the Navy.

Mr. MILLER: I only judged from appearances. The drawings evidently shew it to be the case, and it is a great improvement over the old or present system of fastenings.

Mr. BARNES: I think Mr. Scott means that they should go through in the ordinary way.

Mr. SCOTT: In one of my plans (Fig. 3) the frames are tapped.

Mr. BARNES: I was not aware of that. With regard to Mr. Bettely's channel iron frames, they would be much more troublesome to bend than T irons, and I fear it would be almost impossible in some cases to bend and bevel channel iron frames at the extremities of the ship. I have had a little experience in bending that kind of iron, and know it is difficult; and when you have to bevel it considerably, as well as to bend it, the difficulty is increased. Mr. Bettely's mode of fastening is, I think, bad; the bolts could not be driven so as to insure good fastening.

Mr. BETTELY; I did not shew my fastenings. I will put you right. The planking is first fastened on with a nut to the iron; the ceiling fastening is flush; the bolt holes come through so as to connect the inner and the outer parts; so that first the frame is secured by the screw-bolt to the outer plating, and then the ceiling is also secured, the frame and the outer planking being one perfect combination.

Mr. MILLER: Still there is the same objection, that the bolt cannot fill the holes. There is the great difficulty in all composite vessels. Unless you can have a perfect connection of the bolt with the frame, you will never have a tight ship. With reference to what Mr. Barnes has observed, I may mention for the information of gentlemen here present, that the first iron ship ever built on the banks of the Mersey—the *Richard Cobden*——

The CHAIRMAN: I think you are a little out of order.

Mr. MILLER: I beg pardon. I merely wish to shew that the *Richard Cobden* was framed with T iron, without any difficulty whatever.

Mr. KING: I cannot imagine any reason why these ships should be made composite, except that it is found much cheaper to give strength to a ship with iron instead of wood. I consider nothing more clumsy than the timber of a wooden ship, in several pieces, put together with iron; it is the very picture of weakness; it soon becomes rotten. Therefore, the cheapest kind of construction, in which the requisite strength can be given, is by a complete iron frame, which should be able to stand together, and to resist the injuries of time and of the sea, without any assistance from any wood whatever. I believe, that if we

attempt to strengthen this iron, by any wooden contrivance, such as strong pieces of teak, or plank it over, we merely make a much dearer construction, without materially increasing the strength. The wood, I imagine, should only be used as a medium to keep out the water, just as you would put a cork into a bottle. With regard to the fastening, I have lately built a ship on rather a novel principle. It was a vessel which was to carry copper in an African climate, where the corrosion is exceedingly great, if the copper touches anything like a bolt, or if part of the bottom of the ship is left exposed. It is necessary, therefore, to cut off the inside frame from any contact with the copper. In order to do this, and to fasten on the wood properly to the bottom of the ship, it was fixed on with screws from within, outwards—short screws that did not go through the plank within an inch and a quarter. These screws were so strong that when a strain of nearly a ton was put upon a bolt, it could not be drawn, and the ship throughout was built in that manner. I believe it was more economical, because it took all the strength from the iron, and also it was formed of pine, so that in case there should be the least decay in the pine, it could be taken out at once very economically, and replaced with another piece. I consider Mr. Scott's plan to be objectionable in this respect, that he puts teak—an expensive wood, certainly—to strengthen the iron, which does not want that strengthening, if it is well put together, and therefore makes it very dear. He also screws it on to another piece of timber, and every one knows, that when timber is put against timber in that way, dry rot is the result sooner or later, and it makes it very difficult in cases of repairing, when there is decay, to take it out. If there was a single piece he could easily come at it, and see it. He might either draw his screw, and put in a wooden plug, and replace it with another screw at a little distance from it, or he could take the piece out entirely. As it is at present, when that ship comes to be repaired, the shipowner will find it exceedingly expensive for him. It may be a very good thing for the shipbuilder, but it is a very poor thing indeed for the man who has to pay for the repairs. I therefore consider that that construction is most objectionable. The simpler composite ships can be made, relying entirely for strength upon the iron, and for keeping out the water upon the wood,—that is the principle which will be found most economical, and I believe in the end will be generally adopted.

A Member: Mr. Chairman, I have devoted a great deal of attention to this subject of composite ships. It is, I think, a good plan; but, it has appeared to me for a long time, that in composite ship building, we have used hitherto either too little material in the shape of wood, or too little material in the shape of iron. I think we should have more iron, or more wood, in our composite ships. We want in our mercantile navy to make our shipping property last as long as possible, and approximate as nearly as possible to real property; whereas now, it is very well known that the life of a ship is a very short life indeed. The lives of even our first-class composite ships are exceedingly short. We class our ships for fourteen years; but there are many gentlemen who do not consider that a vessel will at all maintain her class to the fourteenth year. Now, if we can lengthen the life of a ship, and make it approximate to real property, which now it does not, we should attain a very great end and a very great saving. To do this, we require to make our ships much stronger, and to expend much more money upon them in their original construction, than is at present expended. I, for one, do not believe in a cheap ship. If we are to have ships to last, and to be more like real property than they now are, we must put good materials into them. It has occurred to me, that the best composite ship we could have, would be the present iron ship, thoroughly protected and plated upon a wood bottom; and for this purpose, I would not lay on a single layer of wood, but I would lay upon the present iron ships two layers of teak planking, and under the first layer of planking, against the iron, there should be a coating of first-class paint or cement, and

then the first layer of planking should be laid on against that, and bolted to the iron skin of the ship, and over that iron skin there should be another layer of wood planking, so as to make the whole structure completely tight. You would then have a ship, the iron portions of which would never wear out: the ship would be completely protected by the skin of wood planking from any water, and the ship would last an indefinite period. It would be a species of property, in which the merchant would seek to send his goods into any clime or country; and, I think, in the long run, it would be by far the cheapest ship.

Mr. George Barber: I have heard with very great pleasure what has been said on this subject. I have had some experience in the examination of composite ships, and my conclusion is this, that the best composite ship is that which has the ordinary frame of an iron ship well tied together, and a simple wooden bottom. I believe that that is the cheapest ship and the best ship. I see in this room one of the most experienced builders of composite ships, and I think he will bear me out in this opinion. I may state that it was my pleasure to examine some of the tea clippers which were engaged in the late exciting race home from China. I went for the express purpose of finding out defects in those ships, but I assure you I could not find any. Those ships had the most simple construction possible—an ordinary well-strengthened iron frame, and a simple, good wood bottom.

Mr. Welch: I had very lately an opportunity of seeing a composite built vessel on the Clyde which had an ordinary iron-framing, being as much as possible an iron ship before the wood was applied, with this addition, that on the outside of the frame she had diagonal plates of great rigidity fitted. One gentleman observed that the framing is a source of weakness; this could be obviated by placing a diagonal frame in riders outside the first coat of planking. Then by means of two thicknesses, practically, you get a very good ship. Mr. Barnes alluded to the ceiling giving longitudinal strength, but that is dispensed with by the arrangement mentioned, which would also cheapen the construction.

A Member: When iron is applied to these ships it becomes a much better thing than wood alone. I think if the wood is strengthened by the addition of iron, common sense will shew that iron entirely would make a much better job, and a much better arrangement than half and half, because what you gain in the one you lose in the other.

Mr. Rawson: May I be allowed to make an observation with respect to what Mr. Saxby has advanced? In his remarks he asked the question, "What is the best iron?" From what I gathered, I think that Mr. Saxby's observations ought to be brought prominently, either before this or some other Society.

The Chairman: What is the subject you are discussing now?

Mr. Rawson: Which is the best iron.

The Chairman: I do not think that that is the subject which is now under discussion.

Mr. Rawson: I beg your permission to say a word or two. I shall be only a minute.

The Chairman: It is nearly ten o'clock, and we have two more Papers yet to read.

Mr. Rawson: I only wanted to state that I was in connection with Professor Hodgkinson about twenty years ago, and I remember that at that time iron manufacturers from all parts of the kingdom used to send irons to that gentleman to be tested as to their goodness and their marketable value, and I remember that he always had recourse to tearing the irons asunder.

The Chairman: I am afraid you are out of order.

Mr. BETTELY: It might go out that bending frames for a composite ship is a difficult thing. I wish to say that there are now two vessels in which nearly all the frames were bent cold.

Mr. SCOTT: It is so late that I will confine my observations to two or three words, and I do not know that I can do better than read what I stated in the Paper. (Mr. Scott read from his Paper an extract shewing the advantages of his system.) I believe Mr. Bettely's system has been already described to the Institution, if I mistake not, and I think that very strong objections attach to it. A question was asked with reference to the caulking; there would be no difficulty whatever. With respect to setting the frames fore and aft, which I ought to have mentioned, I quite admit that it would be a difficult thing, and the answer to that is, that the number is very considerably less. I do not know that it is necessary to make any further observations. I did not read the Paper with the intention of describing the advantages or disadvantages of composite ships as compared with wood or iron ships, which is a much larger subject; but for the purpose of comparing this particular construction with other constructions which have gone before it.

The CHAIRMAN: I am sure, Gentlemen, you are prepared to give your thanks to Mr. Scott for his Paper, which has most decidedly promoted discussion.

FURTHER RESULTS OF MR. DAFT'S EXPERIMENTS ON THE APPLICATION OF ZINC AS A SHEATHING FOR IRON SHIPS.*

By T. B. Daft, Esq., C.E., Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

In the year 1849 the author became impressed with the importance of preventing iron ships from fouling and protecting them from corrosion.

His first step was to coat the famous Muntz's metal with an insulating material, in order to prevent galvanic action, when such metal was applied to the iron skin of a ship; otherwise the skin of the vessel would be rapidly eaten away, and the yellow metal would foul. He succeeded in firmly attaching sheets of pure vulcanized india-rubber to sheets of yellow metal, and when the coated side of these sheets was placed against the hull of an iron vessel in sea-water, the yellow metal was perfectly insulated from the iron—that is to say, as perfectly as it is possible to insulate metals; for pure india-rubber was, and is, the best insulating material known.

But the insuperable difficulty then was how to securely fasten the sheathing to the hull of an IRON ship. Cements and all sorts of adhesive compounds were tried, but turned out complete failures. Nothing but nails, or such like fastenings, driven into wood, seemed likely to solve the problem.

To make an iron ship and coat it with wood, outside the iron, seemed then, and does now, to the author, the most undesirable combination of strength and weakness, of durability and degradation, of improvement and retrogression, of any combination that can be conceived: if indeed a loss of speed, and an early destruction of the whole fabric were desired, it seems a good plan to ensure both these points.

Therefore, the writer would not content himself with a cement, or anything less than nailing on the insulated material; nor would he succumb to a thick wooden

* Received 12th April, 1867.

sheathing, with all its concomitant drawbacks. And many years elapsed before he could hit upon a plan of nailing into the skin of the vessel in a safe and insulated manner.

At length in the year 1859, he discovered and took out a patent for improvements in ship-sheathing, and, after a few more experiments, fixed upon a plan of drilling partly through the skin, filling the holes up with plugs of "ebonite," or hard india-rubber, and driving nails through the sheathing into the plugs: thus, with the coating of rubber interposed between the yellow metal and the iron, and the nails perfectly insulated in the plugs of "ebonite," the sheathing was quite secure and completely insulated. And in July, 1863, a couple of yellow metal sheets were nailed in this manner on the iron rudder of (s.s.) *Alexandra*, and after several voyages up the Mediterranean they were carefully examined, and found to be perfectly clean, and safely insulated. It is possible that they are in the same condition at this moment, for she continued her voyages, and they were always found clean and bright.

In August of the same year, 1863, two sheets were also nailed on the (s.s.) *Queen of the South*, one sheet on her port bow, and another on her larboard quarter. This vessel made several voyages to India and back, and on examination the sheets were found well insulated and quite clean. Therefore the practicability of sheathing an iron ship with copper or yellow metal was no longer a question; but the expense of drilling and plugging, of insulating the sheathing, added to the extra care required in workmanship, and the high price of the sheathing itself, were circumstances tending much against the system, however desirable it otherwise might be.

But there was another and more serious objection to the use of yellow metal or copper although insulated perfectly—an objection which must remain so long as these two metals are negative electro-chemically to iron—it is this, that an accident at any time, by which the skin of the ship and her sheathing should be brought into metallic contact, would inevitably render the life of the vessel of short duration.

The very worst conditions are imposed upon a ship so sheathed; for metallic contact—and this may be established in a variety of ways by accident or design—would ensure the destruction of the IRON, while the yellow metal would be protected and would foul—events exactly the reverse of those to be desired.

Feeling, therefore, that the system was imperfect, the author continued his experiments, and at last hit upon the application of *zinc;* and at the same time, an improved mode of plating vessels by which that or any other metal may be easily and firmly nailed on. With zinc we have the following advantages:—

It is one-third the price of copper or yellow metal.

It requires no insulating material whatever, or anything interposed between it and the iron.

It electro-chemically protects the iron, and is itself exfoliated, or peeled away, by the same chemical action.

It keeps perfectly bright and clean, and is as durable as copper or yellow metal.

These statements have been proved by experiments instituted by the "Special Committee on Iron" in 1864; and the results being so satisfactory, further experiments on a large scale were, in February, 1865, ordered by the Admiralty to be made in Portsmouth Dock Yard.

Two counterparts of an iron ship's hull were made up of plates about 7 feet long by 3 feet wide, and $\frac{3}{4}$ of an inch thick, with straps of the same thickness at the back, and grooves of $\frac{3}{4}$ of an inch wide were left between the edges of the plates; into these grooves were driven strips of teak, making a fair flush surface and a foundation for nailing on the zinc.

By a mistake these plates were coated with a thickness of felt, saturated with "marine glue," and the sheets of zinc nailed over; but in order to establish metallic contact between the sheathing and the plating representing the ship's side (which contact was interfered with by the glued felt), nails were driven through the sheathing of sufficient length to touch the iron and "turn again."

Besides this, about a dozen of "iron clouts" were used instead of zinc nails, and thus the galvanic action, though feeble, was established, and the zinc kept clean accordingly.

After more than six months' immersion, in distinct parts of the harbour, these plates were taken up for inspection, and found to be clean, and perfectly free from barnacles or weed.

They were then lowered again into the water to complete the twelve months' trial at first ordered to be made. At the end of twelve months it was thought better, by the Admiralty, to keep them submerged another three or four months, in order to give them, as it were, two summers or hot seasons, in which the fecundating principle of marine weeds and animals are mostly developed.

Accordingly they remained to the end of sixteen months under water, when they were hauled up for the inspection of the Lords Commissioners of the Admiralty on the 14th of August last. On that day it was seen by their Lordships—the Right Honorable the President of this Institution being First Lord—that barnacles, weed, and polypi were

clustered about the chains, the frames, and the bare iron, but the zinc was clean and entirely free from them.

The only difference between it and new bright zinc was a slight incrustation of oxide, so slight that it required very close examination to discover it. Every nail head was perfect and visible, and the exceedingly slight coat of oxide which was on close inspection to be seen, was due to the interposition of felt and glue between the zinc and iron, rendering the galvanic action too feeble for the intended purpose. Previous experiments proved that it was desirable to induce an action sufficient to waste, exfoliate, or peel away, 2 ounces per square foot per annum. Now, when the zinc was stripped to ascertain its loss, it was found to have perished only at the rate of 1 ounce per foot per annum.

At this rate zinc of 30 ounces per foot—a moderate thickness for sheathing—would be fifteen years before it would require stripping and re-sheathing.

For many reasons, such a term is far longer than is necessary.

And as by doubling the rate of destruction of the zinc it may be kept perfectly bright and clean for at least seven years, it is desirable to give it metallic contact with the actual skin of the ship, by which the galvanic action is sufficiently energetic to ensure a perfectly clean, smooth surface to the sheathing; while the iron skin of the vessel is kept absolutely free from corrosion.

After the preliminary examination of the two large experiments, the author was permitted to make an experiment with zinc in direct contact with the iron; and in order to shew that the amount of exfoliation of the zinc was perfectly controllable, and depended upon the respective surfaces of zinc and iron in contact, he had a model made so as to expose, as near as possible, equal surfaces of both metals—that is, that the zinc sheathing should cover exactly one-half the face of the iron; and as the zinc has both sides exposed to galvanic action (positively), while there is but one surface of the iron exposed (negatively), it follows that there are equal surfaces exposed to the sea-water, and to galvanic action—under these conditions the zinc perishes at a rate much faster than is desirable, as is evidenced by the experiment; and so potent is the protection afforded to the iron in such a case that the margin of uncoated iron, measuring 4 inches in width in this model, was perfectly free from fouling; there was, after eight months' immersion, only a very thin coating of slime, which came off upon the finger when slightly touched. If the surface of iron coated be equal to one-fourth, the surfaces of zinc would then be one half that of iron, and the destruction would be still greater in a given time, while the protection of the iron from corrosion would be the same; and if

the relative surfaces of zinc and iron exposed in sea-water be as one of the former to four of the latter, then we have the maximum destruction of zinc: but still a complete, or full protection is given to the iron—reduce the surface of zinc to a ratio below this point, and it appears to perish no faster, but there is an enfeebled protection afforded to the iron.

As the writer has devoted himself more or less to this subject for the last twenty years, and almost exclusively for the last seven years, these statements may be relied upon as the results of his experience.

ON WORKING SHIPS' YARDS.*

By H. D. P. Cunningham, Esq., Associate.

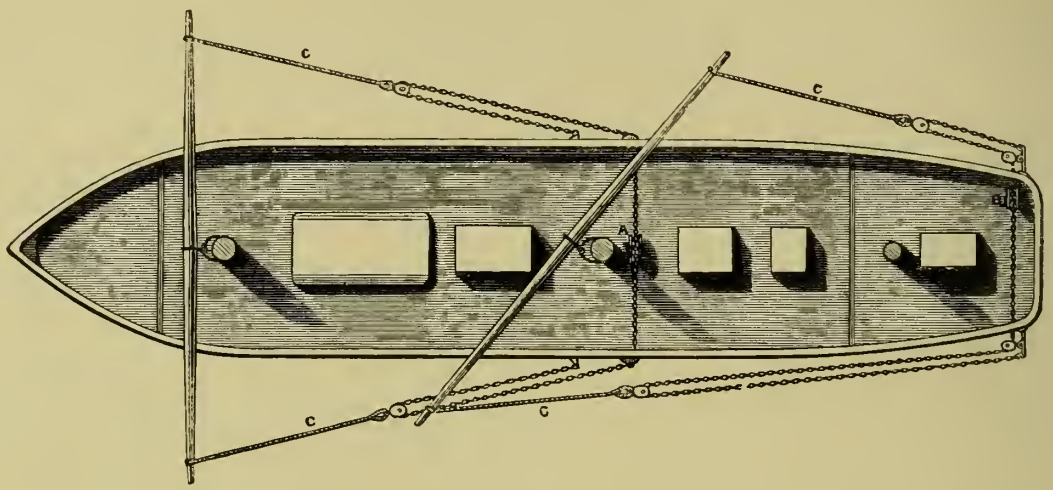
[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

It will be, I am sure, admitted by every officer of the mercantile marine, that there never was a time when everything in the shape of mechanical help was so much needed on board merchant ships as now. The increase in the size of our ships, making, of course, the yards, &c., proportionably larger and heavier to work, and the sad fact, which I believe I am quite right in stating, *viz.*, the falling off of our merchant seamen, in numbers, as well as in physique, point to the necessity of adopting mechanical helps to supplement manual labour in every direction, where such can be applied. It was with these views that some two years back I went into the subject of the bracing round of ships' yards. I knew how very difficult this operation frequently was on board large and ill-manned ships, and how much need there was for some means to help the physical strength in working the yards, and I flatter myself, that in my new method of bracing round ships' yards, I have produced a singularly simple and powerful apparatus for assisting the manual power, and, at the same time, improving the operation with some striking and positive advantages.

In entering upon this work, I struck out on the plan of using chain instead of rope for the working part of the braces, and in lieu of terminating the braces in the usual manner at each side of the ship, I continue the brace over the deck through the brace block on the other side of the yard, bringing back the end to a fixed point on the side of the ship. I have thus a continuous chain. The bight of this chain I pass over a toothed barrel, fitted in a winch or crab, of the construction illustrated by Figs. 7 and 8, Plate VII., being different views of the brace machine. It will be seen that the chain passes under level rollers at each end of the machine and then over the barrel alluded to, when the links are held or clutched by the teeth or indentations. When the barrel is turned round, the chain is drawn in on one side and passed out on the other side. Lever stoppers are placed at the ends of the machine for stopping and controlling the chain. These stoppers are seen at *a* and *b*. For a fore yard, I place this machine

* Received April 12th, 1867.

at A in the annexed woodcut, and for a main yard it is usually placed on one side of the poop, at B. It is almost needless for me to explain the operation of bracing round yards by this method, as its extreme simplicity is its own description. However, on turning round the winch handle of the machine, the chain is drawn in on one side and passed out on the other side of the ship, and thus the yard is braced round in whichever direction may be required. When bracing sharp up, a certain amount of



slack will exist. This is taken up by putting down the lee stopper, and heaving in on the weather chain until the brace is taut, when the weather stopper is put down and the yard secured.

The help that this simple invention affords may be estimated as one to five; that is, one man can certainly do the work of five, or even more. But, perhaps, I had better quote some expressions from those who have had the practical working of my invention. Mr. Martin, Trinity pilot, writes to say that in working round to Spithead in strong winds in the ship *Dragon*, he found three men sufficient to work the foreyard, sparing the rest to work the fore tack and sheet—an important advantage in working ship in a confined channel. The commander and officers of the same ship write from Calcutta that they found it to be a great advantage in light and variable weather when taken aback, as so many more men of the watch can be spared to attend to the other sails. Mr. Dames, the Trinity pilot, writes in the highest terms of my braces in working the ship *Colonial Empire* down Channel. The commander of the ship *Roseneath*, of Glasgow, describes that in a stormy passage to Montreal he found three hands sufficient to work his foreyard. In light winds two hands can brace it round with ease. This ship is 1,000 tons. Mr. Thomas Martin, Trinity pilot, in reporting on the working of the braces on a ship he had taken down Channel, says:

"I should very much like to have it on board every ship I pilot from London." The commander of the ship *Colonial Empire*, writing from Sydney, after expressing himself very strongly as to the advantages he found from the invention during a heavy beat down Channel, points out this striking benefit. He says: "One great advantage "in heavy weather of these braces is that the men are in amidships instead of the "scuppers, and consequently are much drier." The commander of a very large ship, the *Indian Chief*, 1,800 tons register, arriving at Liverpool from Bombay, recommends it as a useful invention for saving labour and helping in the navigation of the ship. This ship's foreyard was very heavy. The master of the ship *St. Vincent*, with fore and main yards fitted, is very warm in his praises. He says, "Words are "superfluous to describe the advantages of your patent braces over the old-fashioned "plan. And he knows it would be to the interest of every shipowner to have them." Mr. Cargill, an old ship-master, who has commanded ships for forty years, states, with reference to navigating the ship *Christina Thompson* from Aberdeen to London, in very heavy weather beating all the way, that he found four hands sufficient to work the foreyard with ease; he says that he considers the invention a very valuable one. This ship is 1,079 tons register.

The commander of the China clipper ship *Maitland*, fitted fore and aft, after his return from a voyage to China, says: "They have many advantages over the old "plan: you can spare so many men to the tacks and sheets: the *braces are always clear*, "and the men amidships instead of in the lee scuppers. I hope never to be without "them. The braces will last for years, there being so little wear and tear." Another pilot, Mr. William Loughton, says: "I should like to have it on board every ship I "take from London." I will conclude these expressions of opinion of this invention by quoting a striking advantage pointed out to me by Admiral Sir William Martin, which seems to have escaped the notice of others. I am sure Sir William will pardon my making use of his valuable suggestion. He says: "For head braces they are "most important. There is an advantage they have which I well recollect having "mentioned before:—the great use they would be in weighing anchor when the ship "casts the wrong way. At such a time there is the urgent want to get the anchor "up to prevent hooking other ships' cables, and at the same time probably to have "to brace round the yards."

I may mention that Sir William Martin inspected the ship *Dragon* on her arrival at Spithead, and so was familiar with the invention.

I will not, however, now detain you longer. I believe the subject must be an interesting one to naval architects as well as to shipowners.

DISCUSSION.

A MEMBER: Will you allow me, Sir Edward, to ask Mr. Cunningham why he employs two things to do the same thing? I believe he can have as powerful a crab as he pleases, quite adequate to turn the yard; notwithstanding that, he puts a pulley upon it, which of course very much augments the expense. He has more rope to pull in—a very dear article, let me say, always, and I think it might be done equally well with a good large crab. In fact, this is the only thing that prevents me from adopting the invention. I must express myself much indebted to Mr. Cunningham for his patent top-sails and other contrivances, but I think if he would adopt a simple winch instead of doubling it over with a pulley it would be more economical, and shipowners would be able to adopt it more readily than they can at present.

Mr. CUNNINGHAM: Will you kindly explain what you mean by the double pulley first?

A MEMBER: Mr. Cunningham is aware that there was a time when ships sailed without any pulleys at all; and about a century ago, it was thought a great invention when they were added to a ship, but I think that they are carried too far, and that to a great extent we can do without them.

Mr. CUNNINGHAM: In some cases the masters of ships single their braces. Instead of working upon the two they work upon the single one, but they lose power by it. What I can do with two parts with one man of course would require two or three by the single.

A MEMBER: Not if you get a more powerful crab?

Mr. CUNNINGHAM: Yes.

Mr. HOLMAN: I happen to be in a position to be able to corroborate part of what Mr. Cunningham has said. I happened to be in Liverpool when the *Indian Chief* arrived from Bombay, and I conversed both with the mate and the captain on the subject of this winch, and made various enquiries; so convinced was I of its value, that I recommended it in a ship of about 1,000 tons register, and I added, "If it does "not answer after the first voyage, you may charge me with the cost of the machine."

RECENT IMPROVEMENTS IN THE CALCULATION OF THE STATICAL STABILITY OF SHIPS.*

By Charles W. Merrifield, F.R.S., Hon. Secretary and Associate, I.N.A.

[Read at the Eighth Session of the Institution of Naval Architects, April 13th, 1867; Joseph H. Ritchie, Esq., Mem. Council, in the Chair.]

The calculations of a ship are never considered complete unless her stability has been ascertained. The well-known rule of the metacentre has not been thought sufficient, because it makes no allowance for the change of form which the immersed portion of the ship undergoes in heeling, or even for the change of form of the water-line. It is therefore only accepted as a first approximation, and it is only in ships which closely approach to well-known forms that any security can be felt that their stability will not decrease as they come over, instead of increasing as the sine of the inclination.

The usual plan has been to ascertain the righting moment by calculating the moments and masses of the "ins and outs," or immersed and emersed wedges. But this involves an excessive amount of arithmetical work, and even Mr. Barnes's improved method has not brought it within the practical limits of time at the disposal of the ordinary draughtsman. Moreover, it only gives the moment for one particular inclination, and there is nothing in the calculation, to suggest an approximate value for intermediate or outside angles. The result of the calculation is therefore inadequate to the labour spent upon it, even when there is time to do it at all.

It occurred to me that we might, instead of going through this process, start from the metacentre as a first approximation, and then introduce the correction due to a definite inclination, by some method which should be sufficiently exact for the object, and which should evade the calculation of the wedges. I found such an one, and communicated it to the Royal Society last February. I am happy to say that Professor Rankine has since devised an improvement, which makes it a thoroughly practical method. It has been tried in the School of Naval Architecture, and it has been found

* Received 10th April, 1867.

satisfactory in respect both of accuracy and simplicity. I shall not trouble the Institution by reading formulæ: these and the arithmetical example, I shall reserve for an Appendix, and meanwhile I will try to give a sketch of the method.

I must first remark that the stability of a body floating in water may be reduced to that of a body, with a curved base, resting on a table, like a Chinese tumbler, in fact. The determination of the stability of a ship really resolves itself into the determination of the representative curve which is to rest on the table. The metacentric theory supposes this curve to be a circle, or cylinder, of which the centre is called the metacentre. If you know where the centre of gravity of a cylinder is, it is an easy geometrical problem to find out all about its stability.

But it is not necessary that this representative should be a circle at all. We have reason for knowing that it cannot have any corners or gaps, and a circle is a very good approximation for extremely small angles. But it may take a sharper curl as you move away from the middle point, and then its stability would not be the same as that of a loaded cylinder. That is exactly what we want to test.

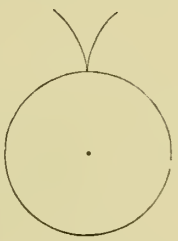
Let us observe what the metacentric circle does for us when we try to draw our representative curve with the help of a batten. We get a starting-point and a starting direction, and we know how much the batten has got to be bent at the starting-point. This is some help. If now we get *the same things* farther on, within moderate limits, we might say the curve was pretty well determined—that is to say, that if (say at a difference of inclination of 10°) we could get a fresh point, a fresh direction, and a fresh curvature, we should find it very difficult to draw more than one fair curve between them. I mean that, if you drew two, you would want a microscope to distinguish them. Now this is what can be done by a complete use of the calculations of the "ins and outs." But I never heard of its being pushed to this extent. Indeed, it would require a great deal of very abstruse calculation to do it; and for this reason I consider the process wanting in economy of labour. It seemed to me that enough would be done if, instead of determining, in addition to the common metacentre, a point, a direction, *and* a curvature, I determined one of the three conditions, instead of all three. And since the whole of the measurements and calculations about ships are only approximate, I did not feel at all sure that we were not putting too fine a point upon it by going beyond one such condition. Actual trial has shown that I am right in this surmise, at least in so far as concerns ordinary ships; for the stabilities got out (1) by my method as it first appeared, (2) with Mr. Rankine's improvement, and (3) by Mr. Barnes's method of taking

the "ins and outs"* differed by a very small fraction, well within the probable limits of accuracy of either method. The new method gives the result in a handier form, and with less than half the work of the old method.

Geometrical simplicity, mechanical simplicity, and simplicity of calculation, are three things which are closely allied, but do not go very far together. My method followed the first, and only approximated to the two others. Professor Rankine hit both of these, and approximated to the first. I need hardly tell you which answers the best. I shall ask you to follow me in a little mechanical explanation which will, as I think, set these methods in a very clear light.

All questions of the statical stability of ships may be resolved into the case of a pendulum. If the pendulum be suspended from a point, that is metacentric stability, and the righting couple varies with the sine of the inclination, or disturbance from the vertical. But if the pendulum string, instead of being fixed to a pivot, winds off a cheek, the curvature of the cheek may be so managed as to make the bob describe any given curve, and thus represent any given ship. I said to myself, let the bob describe the next simplest curve to the circle, namely, an ellipse or other conic section; and let the calculations of the ship determine what conic section, exactly, it shall be.

But Professor Rankine said:—"You don't want the curve described by the bob; "your mechanical conditions are settled by the cheek the string winds off [the evolute]. "Let that be the simplest you can get to fulfil your conditions, and let the bob take care "of itself, and so you will get a simpler arithmetic;" and he thus introduced a marked improvement. His idea was to make the cheek, or rather the pair of cheeks, the cusp of the involute of the circle. If you want to describe this curve, take a reel of cotton and tie the end to a pencil; as the cotton winds off, your pencil will trace the involute. Now this cheek, in my method, was the evolute of a conic section, instead of the involute of a circle, and you may well ask me how two such different methods can possibly agree. The answer is, that either cusp is a refinement on the metacentric point, and that their variable elements are determined from the ship itself, so that within reasonable limits of heeling, the curves which they trace out do not sensibly differ from one another, neither do the mechanical results which follow from them.



Besides this, Professor Rankine's method gives the departure from isochronous

* See *Transactions of the Institution of Naval Architects*, Vol. II. (1861), p. 163.

rolling, and it may be as well to notice in this place that no ship of ordinary form approaches at all to the condition of isochronism.* That condition is, that the centre of weight should be at the centre of the circle from which the involute is drawn. Now, in the examples which have been tried in the School, the centre of the circle came out considerably below the keel of the ship. This is an impossible place for the centre of weight, which is usually not far from the actual water-line.

I have still to explain the way in which this second approximation (regarding the metacentre as a first approximation) is obtained and applied. If our object were to draw the representative curve of a ship's stability with a penning batten, the simplest idea would be to find another point on it. But, as has already been observed, it is not that, but the mechanical property which is primarily wanted. For this purpose I give the ship a definite inclination, by what is tantamount to shifting her weights internally. I then find a new metacentre for this position, as if she were an unsymmetrical ship, masted and loaded for this skew water-line. The want of symmetry makes the calculations slightly different from the usual ones, and their exact nature will be stated in the Appendix. All I need state here is that our object is, first, to find the moment of inertia of the skew plane of flotation about a longitudinal axis passing through its centre of gravity; and secondly, to divide this by the displacement, which remains constant. We then introduce this into some simple formulæ for work. These formulæ involve the sine of the inclination and the arc corresponding to the sine, but they are exceedingly easy to use, and also to apply to any other inclination than the one calculated for.

We have still to determine our skew flotation, subject to the condition that the displacement shall remain unaltered. For this purpose I use the mean section of the ship, which I obtain as follows:—The ordinary calculation gives me the areas of all the level sections. I divide these by the whole length of the ship on the water-line, and use the quotients as ordinates for setting off the mean section. It is obvious that, so far as regards displacement, upright, this is really an exact mean section, and is equivalent to the transverse section of a prismatic or cylindrical body whose displacement at all upright flotations exactly corresponds with that of the ship. Now, for skew displacements, it is a very good approximation, and as such I use it for drawing a skew water-line. I draw upon this mean section a skew water-line, true to the required angle, but by guess as to the point at which it crosses the middle line, or line of symmetry. Then I measure the immersed and emersed triangles (a very much easier thing than the in-and-out wedges), and correct it if these disagree. I then transfer the line to the body plan, and run off my ordinates.

* Further experience throws some doubt on the generality of this observation, which was written before the example appended to this Paper had been worked out.

The Appendices will contain full explanations of the mathematical part, and also the practical working details, with an example. One of the Appendices will contain a geometrical method of exhibiting the statical stability at all angles, and for all positions of the centre of weight, provided the draught of water remains constant. The question of the (so called) dynamical stability—that is to say, the work done in heeling the vessel through a given angle—will also be treated. I do not go into this subject before the Meeting, because it is a bit of mere mathematical curiosity, which has hitherto received no useful application, although some fanciful comparisons have been occasionally derived from it. Still it may become of real use some day; and as it is very easy to get at, it would be a piece of idleness to neglect it altogether.

I now come to the loose points in the process, and I must first say that I don't think the approximation is one of them. The mean section is very good, as I think, and so is the use made of the further condition derived from the skew metacentre. I freely admit that they are not, in theory, so accurate as the "ins and outs," or wedge methods. But I am of opinion that the new method is as accurate as the measurements can be. For, be it remembered, that these are not taken from a ship as she sits in the water, but from a sheer draught, of which some points only have been settled by the designer, or else taken off from a ship in dry dock, and all the rest of the drawing has been, as it is called, *faired;* that is to say, settled arbitrarily by the draughtsman. Now, if the theoretical method of calculation be as accurate as the drawing off which it is to be taken, I don't think I need do anything more than appeal to its facility.

If the data were sufficiently accurate, it is certain that the method of the "ins and outs" ought to give us very much more information than has ever been exhibited by means of it. But it is these data which fail; and as its labour exceeds that of the new methods, in so far I think it involves "lost work."

Before concluding, allow me to point out to the younger gentlemen present the direction in which our calculations about statical stability are chiefly defective. I will not say that our direct methods have *no* room for improvement; but having regard to their now very simplified form, and to the complex nature of the surfaces involved, it is clear that there can be but a very small margin of saving to be effected by working in the direct line hitherto followed. Now, our existing work fails in this—that a ship at two different draughts is two ships, and a ship at the same draught, but with two different trims, is again two ships—for all purposes of the calculation of statical stability. Every difference of draught or trim puts us through a fresh calculation. It might be imprudent to prophesy that it is in this direction that the next discoveries will be made; but I hazard nothing in telling my younger friends, that here at least they will find unbroken ground.

APPENDICES.

I.—Original Account of the Method. Reprinted by permission from the "Proceedings of the Royal Society."

II.—Professor Rankine's Note. Similarly Reprinted from the same source.

III.—Reduction of the Method to Practice.

IV.—Example worked in the Royal School of Naval Architecture, by William Richards and J. W. Rowse.

V.—Geometrical Representation of a Ship's Stability.

APPENDIX I.

On a New Method of Calculating the Statical Stability of a Ship, by Charles W. Merrifield, F.R.S., *Principal of the Royal School of Naval Architecture.*

The time required for the calculations of the stability of ships has practically restricted the ordinary draughtsman to the use of the metacentre. This implies that the locus of the centres of buoyancy cuts the transverse midship plane in a curve which may be treated as a circle; and this is only true in general, for very small limits of inclination. In some particular cases it has been felt desirable to supplement this by computing the moment of stability at some definite angle of inclination, by means of the "ins and outs," or immersed and emersed wedges. But this has only been applied to one selected inclination, generally of 10° or 14°; and owing partly to this and partly to the very scant time left available to the skilled draughtsman or calculator, this has never been a part of the ordinary work of the computation of a ship's quantities. For this reason it becomes of great consequence to find some method of getting at the stability, with an amount of extra work which should not exceed that of the ordinary sheet known as the "sheer-draught calculation."*

A method has occurred to me by which, as I think, this object may be attained. Upon conferring with some of my students,† who have suggested and removed certain difficulties of detail, we think we see our way, by an easy calculation, to place the whole account of a ship's statical stability in the hands of any person who understands simple equilibrium, either in an algebraical or geometrical form, as he may prefer.

It will take some time, with my present occupations, to prepare detailed examples; but as the method is complete in respect of principle, I have thought it best to bring it at once before the Society.

The fundamental assumption is, that the locus of the centres of buoyancy can be sufficiently represented by a conic. The stability is then measured by the perpendicular, from the centre of actual weight, on the normal due to the inclination. The chief step, therefore, is to find the conic, of which I may remark, we already know the vertex, and

* See *Shipbuilding, Theoretical and Practical*, by Watts, Rankine, Barnes & Napier, p. 46, for the sheer-draught calculation commonly used in this country.

† Messrs. Deadman, Elgar, John, and White.

the tangent and curvature at the vertex; for these are given by the ordinary calculation of the centre of buoyancy and the metacentre. Now I observe, that the conic is completely determined if we can find the length of another radius of curvature corresponding to a known inclination. This is obtained by finding the moment of inertia about one of its principal axes (longitudinal) of the plane of flotation at the inclination. This, divided by the unaltered displacement, gives the radius of curvature required.

But the chief practical difficulty lay in finding the means of drawing an inclined water-line across the body plan, so as to give an unaltered displacement. This I have at length succeeded in overcoming, as follows:—

The sheer-draught calculation gives us *inter alia*, the areas of the level sections, belonging to the upright position, as rectangles. Now, if we make one side of each of these equal to the length of the ship, their breadths form a series of ordinates for a curve of mean section; that is to say, the transverse section of a cylindrical body, of which the displacement at any level immersion will be the same as that of the ship. We then make out a scale of displacement for this section at various immersions, for a selected inclination, taking care to measure the immersions on the middle line of the original body plan. By this means the finding of any water-line at the selected inclination is reduced to a problem of plane geometry; and it is obvious that the place of the water-line so found will be a very close approximation to that of the required plane of flotation in the ship.

The calculations are as follows:—

1. Take out the horizontal areas from the sheer-draught calculation, and divide each by the ship's length. Set them off right and left from a vertical line at their present vertical interval, and draw a curve through their ends.

2. Any practised draughtsman will have little difficulty in drawing, at sight, an inclined line of flotation which shall give an unaltered immersed area on this mean section. He can verify it by measuring the immersed and emersed triangles obtained by his first guess, and make the correction due to the difference, if they do not agree.

3. In strictness, the more accurate course would be this:—through each of the vertical stations draw right lines at the selected angle. Thence, by Simpson's Rule, form a scale of areas, ending at the highest inclined water-line. Use the vertical interval of the upright displacement, and neglect the cosine of the inclination. Then divide the upright displacement by the ship's length and by the cosine of the inclination, and find to what immersion this displacement corresponds in the scale of inclined areas. But this is needless, unless the calculations have to be made for different draughts of water.

4. Use this immersion to draw the inclined plane of flotation in the body plan.

5. Calculate the area, common moment, and moment of inertia of this plane, about the longitudinal axis, formed by its intersection with the original plane of flotation upright.

6. Transfer this moment of inertia to the longitudinal axis passing through the centre of gravity of the inclined plane of flotation.

7. Divide the moment so found by the displacement. This will give the radius of curvature of the locus of the centres of buoyancy, corresponding to the selected inclination.

The conic is now implicitly determined. It remains to show what use is to be made of these data.

Let ρ_θ be the radius of curvature, corresponding to the angle θ, made between the normal and axis of a conic; then

$$\rho_\theta = \frac{a(1-e^2)}{(1-e^2\sin^2\theta)^{\frac{3}{2}}}, \quad \rho_0 = a(1-e^2).$$

From these we obtain

$$e^2 = \frac{\rho_\theta^{\frac{2}{3}} - \rho_0^{\frac{2}{3}}}{\rho\theta^{\frac{2}{3}}\sin^2\theta}, \quad \ldots\ldots(a)$$

$$1-e^2 = \frac{\rho_0^{\frac{2}{3}} - \rho_\theta^{\frac{2}{3}}\cos^2\theta}{\rho_\theta^{\frac{2}{3}}\sin^2\theta}, \quad \ldots\ldots(b)$$

$$a = \frac{\rho_0\rho_\theta^{\frac{2}{3}}\sin^2\theta}{\rho_0^{\frac{2}{3}} - \rho_\theta^{\frac{2}{3}}\cos^2\theta}, \quad \ldots\ldots(c)$$

$$ae^2 = \frac{\rho_0\left(\rho_\theta^{\frac{2}{3}} - \rho^{0\frac{2}{3}}\right)}{\rho_0^{\frac{2}{3}} - \rho_\theta^{\frac{2}{3}}\cos^2\theta}; \quad \ldots\ldots(d)$$

and these afford the means of calculating all the elements of the conic.

Now let us take any other inclination ϕ: we may calculate ρ_ϕ from the foregoing value of e^2 by means of the formula:—

$$\rho_\phi = \frac{\rho_0}{(1-e^2\sin^2\phi)^{\frac{3}{2}}}. \quad \ldots\ldots(e)$$

Now, if λ be the distance of the centre of gravity of the ship below the metacentre of the upright position, and p the perpendicular from the centre of gravity on the normal of the conic in the inclined position, we shall have

$$\frac{p}{\sin\phi}=\lambda+\frac{\rho_0^{\frac{2}{3}}(\rho_\phi^{\frac{2}{3}}-\rho^{0\frac{2}{3}})}{\rho_0^{\frac{1}{3}}+\rho_\phi^{\frac{1}{3}}\cos\phi}; \quad \ldots\ldots\ldots\ldots\ldots\ldots(f)$$

and $p \times D$ is the moment of stability, D being the displacement.

Strictly, it is only necessary to use the formulæ (a), (c), (f) in actual work. Formula (f) shews clearly how an alteration in the position of the weights affects the stability. If λ be altered, the altered value of p is obtained (geometrically) by a very obvious construction.

In Mr. Scott Russell's treatise on "Naval Architecture," p. 604, it is shown how the stability may be obtained by geometrical construction when the conic is known.

It is worth while to remark that the condition that the conic should be a hyperbola, a parabola, or an ellipse, is—

$$\rho_0 <, =, \text{ or } > \rho_\theta \cdot \cos^3\theta;$$

and whether the ellipse is referred to its major axis, becomes a circle, or is referred to its minor axis, depends upon whether

$$\rho_0 <, =, \text{ or } > \rho_\theta;$$

θ having any value whatever within the limits of continuity.

It is to be observed that this method only applies on the supposition that there is no abrupt discontinuity. The immersion of the gunwale, for instance, would vitiate it. But in ordinary ships, experience leads to the conclusion that a conic would be a very accurate representation of the locus of centres of buoyancy within all reasonable limits.

I have not waited to try the method throughout upon a specific example. But every step is separately well known; most of the steps familiarly so, within my own experience. My *estimate* of the extra amount of work is, that it would be rather less than would be involved in making an independent calculation of the ordinary sheer-draught work. I shall have an immediate opportunity of verifying this in my School; but I wished to announce the method publicly before beginning to teach it.

APPENDIX II.

Note on Mr. Merrifield's New Method of Calculating the Statical Stability of a Ship. By W. J. Macquorn Rankine, LL.D., F.R.S.

On the 24th of January, 1867, a Paper was read to the Royal Society by Mr. C. W. Merrifield, F.R.S., Principal of the Royal School of Naval Architecture, shewing how,

by determining the radii of curvature of the locus of the centre of buoyancy, or "metacentric involute," of a ship in an upright position, and at one given angle of inclination, a formula may be obtained for calculating to a close approximation her moment of stability at any given angle of inclination, on the assumption that the metacentric involute can be sufficiently represented by a conic.

It has occurred to me that the latter part of the calculation in Mr. Merrifield's method might be simplified by assuming for the approximate form of the metacentric involute, not a conic, but the *involute of the involute of a circle;* the locus of its centres of curvature, or "metacentric evolute," being assumed to be the involute of a circle.

The involute of the involute of a circle is distinguished by the following property. Let r be the radius of the circle, ρ_0 that radius of curvature of the involute of the involute which touches the involute at its cusp, and ρ another radius of curvature of the same curve, making the angle θ with the radius ρ_0; then

$$\rho = \rho_0 + \frac{r\,\theta^2}{2} \qquad \ldots\ldots(1)$$

Having found, then, the radii of curvature of the metacentric involute in an upright position, and at a given angle of inclination θ_1, let ρ_0 and ρ_1 be those radii respectively; then make

$$r = 2\cdot\frac{\rho_1 - \rho_0}{\theta_1^2} \qquad \ldots\ldots(2)$$

This will be the radius of the required circle; and its positive or negative sign will shew whether it is to be laid off downwards or upwards from the metacentre. For any given angle of inclination, the radius of curvature of the metacentric involute will be given by equation 1, which may also be put in the following form:—

$$\rho = \rho_0 + (\rho_1 - \rho_0)\frac{\theta^2}{\theta_1^2} \qquad \ldots\ldots(3)$$

Let λ be the depth of the ship's centre of gravity below her metacentre, and p the perpendicular let fall from that centre of gravity upon the radius of curvature of the metacentric involute at any given angle of inclination θ; then

$$p = (\lambda - r)\sin\theta + r\,\theta; \qquad \ldots\ldots(4)$$

and the moment of stability is

$$p \times \text{Displacement.} \qquad \ldots\ldots(5)$$

It is obvious that the condition of *isochronous rolling* is, that $\lambda - r = 0$; that is to say, that the centre of the circle which is the evolute of the metacentric evolute shall coincide with the ship's centre of gravity; a proposition already demonstrated by me in a Paper read to the Institution of Naval Architects, in 1864, and published in their *Transactions*, Vol. V., page 35.

Glasgow University, 20*th Feb.*, 1867.

APPENDIX III.

Reduction of the Method to Practice.

The first thing is to find where the water-line comes when the vessel is listed over to a certain angle, the displacement of course remaining unaltered.

For this purpose the area of each level section is divided by its length, and the quotient is treated as a mean breadth. These mean breadths are set off right and left of a vertical line, and a curve run through their extremities. This gives a mean transverse section on which it is easy to draw an inclined water-line, which shall cut off the same area as the load-water-line. It is necessary for this purpose that some horizontal sections above the load-water-line should be calculated. The line thus obtained is transferred to the body plan.

The accuracy of the new water-line may be tested on the mean section by calculating the areas of the in-and-out triangles. If these differ, an area corresponding to the difference may be set off by a fresh line drawn above or below the other, according to the sign of the difference—the rule being, to get the area cut off by the inclined water-line equal to that belonging to the load-water-line.

The second step is the determination of the unsymmetrical metacentre due to the inclined position.

In a vessel floating symmetrically, we have simply to find $\int \frac{1}{3} y^3 \, dx$ from the middle line of the plane of flotation. We divide the *double* of this by the displacement, to get the height of the metacentre above the centre of buoyancy.

When the two sides of the ship are unsymmetrical, the same integral has to be taken up one side and down the other of an axis passing through the centre of gravity of this plane. Practically, we find the following integrals about an arbitrary longitudinal axis :—

$\int y \, dx$ for area.

$\int \frac{1}{2} y^2 \, dx$ for moments.

$\int \frac{1}{3} y^3 \, dx$ for metacentre.

We find the position of the centre of gravity from the first two, and we then transfer the moments of inertia in the third integral to an axis passing through that, by means of the formula

$$M_0 = \int \tfrac{1}{3} y^3 \, dx - \left(\frac{\int \frac{1}{2} y^2 \, dx}{\int y \, dx} \right)^2 \int y \, dx$$

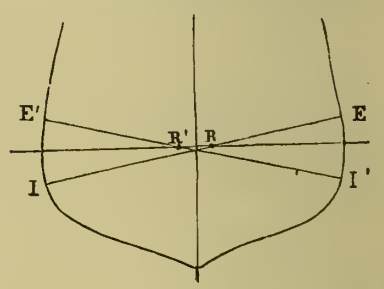
$$= \int \tfrac{1}{3} y^3 \, dx - \frac{\left(\int \frac{1}{2} y^2 \, dx \right)^2}{\int y \, dx}$$

taken between proper limits. The integrals $\int \frac{1}{3} y^3 \, dx$ and $\int y \, dx$ are the arithmetical sums of the integrals on the two sides of the axis: the $\int \frac{1}{2} y^2 \, dx$ is the arithmetical difference. To make this clear we may write it as follows: let Y_r represent the ordinates taken on the right hand side, and Y_l those on the left-hand side of the arbitrary axis, then

$$M_0 = \int \tfrac{1}{3} Y_r^3 \, dx + \int \tfrac{1}{3} Y_l^3 \, dx - \frac{\left\{ \int \frac{1}{2} Y_r^2 \, dx - \int \frac{1}{2} Y_l^2 \, dx \right\}^2}{\int Y_r \, dx + \int Y_l \, dx}$$

And this value has to be found and divided by the displacement, which of course remains the same, whether the vessel be upright or listed.

We then enter them in a table arranged as in the example given below, taking the squares and cubes from a printed table,* and integrating by Simpson's multipliers. We must take care not to get into confusion about the after and fore-bodies in the body plan with this division. Thus, in the accompanying drawing, the ordinates R E and R′ E′ and the intermediate ones belong to one side, and R I and R′ I′ to the other.



We then find M_0 by means of formula, and divide it by the displacement. The next thing is to determine the finite stability from this datum.

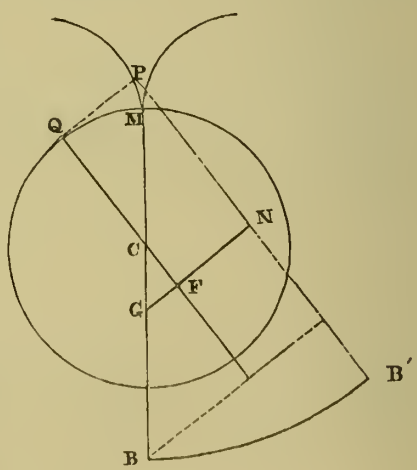
We will first give the geometry of Professor Rankine's formula:—

Let M P be the curve of metacentres, or metacentric evolute.

M Q be the circle of which it is assumed to be the involute.

B B′ be the curve of centres of buoyancy, or metacentric involute.

B P B′ be the angle of the ship's inclination ($= \theta_1$, suppose).



Since Q P winds off the circle, it is obvious that it is perpendicular to Q C and equal to the arc Q M. It is also perpendicular to the arc M P and its tangent P B′. Hence C Q is parallel to P B′ and Q C P $= \theta_1$. Hence Q P = arc Q M $= r \, \theta_1$.

* *Barlow's Tables of Squares, Cubes, Roots, and Reciprocals.* London: Walton & Maberly.

Having found, then, the radii of curvature of the metacentric involute in an upright position, and at a given angle of inclination θ_1, let ρ_0 and ρ_1 be those radii respectively; then make

$$r = \frac{2\,(\rho_1 - \rho_0)}{\theta_1^2}$$

This will be the radius of the required circle; and its positive or negative sign will shew whether it is to be laid off downwards or upwards from the metacentre. For any given angle of inclination θ, the radius of curvature corresponding to that inclination will be given by the equation

$$\rho = \rho_0 + \tfrac{1}{2}\, r\, \theta^2, \text{ or}$$
$$\rho = \rho_0 + (\rho_1 - \rho_0)\, \frac{\theta^2}{\theta_1^2}$$

Moreover, since Q P is the radius of curvature of the curve P M at P, the arc P M is obtained from the well-known general formula $d\,s = \rho\, d\,\theta$.

$$\int_0^\theta \mathrm{Q\,P}\, d\,\theta = \tfrac{1}{2}\, r\, \theta_1^2$$

Let us call P B′, ρ_θ and M B, ρ_0; then

$$\rho_\theta = \rho_0 + \tfrac{1}{2}\, r\, \theta_1^2$$

Now let G be the centre of weight, and M G $= \lambda$; draw G F Z $\perp$ P B′. Then

$$\mathrm{G\,C} = \lambda - r$$
$$\mathrm{G\,F} = \mathrm{G\,C} \sin\theta = (\lambda - r) \sin\theta$$
$$\mathrm{F\,Z} = \mathrm{Q\,P} = r\,\theta$$
$$p = \mathrm{G\,Z} = \mathrm{G\,F} + \mathrm{F\,Z} = (\lambda - r) \sin\theta + r\,\theta$$
$$p = \lambda \sin\theta + r\,(\theta - \sin\theta)$$

Now $\lambda \sin\theta$ gives metacentric stability, and the rest of the formula gives the correction for the second metacentre. We may write this again as

$$p = \lambda \sin\theta + 2\, \frac{\rho_1 - \rho_0}{\theta_1^2}\, (\theta - \sin\theta), \quad \text{or}$$
$$p = \lambda \sin\theta + 2\,(\rho_1 - \rho_0)\, \frac{\theta}{\theta_1^2} - 2\,(\rho_1 - \rho_0)\, \frac{\sin\theta}{\theta_1^2}$$

Of these three terms, each has to be calculated separately.

To get the dynamical stability, integrate the above from $_0$ to θ. We obtain

$$\mathrm{Z} = \lambda\, \mathrm{versin}\,\theta + \gamma\,(\rho_1 - \rho_0)\, \left(\frac{\theta}{\theta_1}\right)^2 - 2\,(\rho_1 - \rho_0)\, \frac{\mathrm{versin}\,\theta}{\theta_1^2}$$

If the angles are given in degrees, as they usually are, we must introduce the

length of the arc of one degree. Calling this d, we have, when θ and θ_1 are in degrees,

$$p = \lambda \sin\theta + \frac{2(\rho_1 - \rho_0)}{d}\frac{\theta}{\theta_1^2} - \frac{2(\rho_1 - \rho_0)}{d^2}\frac{\sin\theta}{\theta_1^2}$$

$$z = \lambda \operatorname{versin}\theta + (\rho_1 - \rho_0)\left(\frac{\theta}{\theta_1}\right)^2 - \frac{2(\rho_1 - \rho_0)}{d^2}\frac{\operatorname{versin}\theta}{\theta_1^2}$$

$$\text{also} \begin{cases} \log.\frac{1}{d} = 1{\cdot}7581226 \\ \log.\frac{2}{d} = 2{\cdot}0591526 \\ \log.\frac{2}{d^2} = 3{\cdot}8172753 \end{cases}$$

APPENDIX IV.

Calculations of Stability, Statical and Dynamical, of a Ship of the "Warrior" class, by Mr. Merrifield's Method, with Professor Rankine's Improvement. Example worked in the Royal School of Naval Architecture, by Wm. Richards *and* J. W. Rowse.

(A.) Calculation of the Integrals for the Water Section inclined at an angle of 10°.

IMMERSED.

No. of Ordinates.	Ordinates.	S.M.	Products.	Squares.	Products.	Cubes.	Products.
1	1·6	1	1·6	2·56	2·56	4·1	4·1
2	1·9	4	15·6	15·21	60·84	59·3	237·2
3	6·3	2	12·6	39·70	79·40	250·0	500·0
4	8·5	4	34·0	72·30	289·20	614·1	2456·4
5	10·2	2	20·4	104·0	208·00	1061·2	2122·4
6	11·5	4	46·0	132·3	529·20	1520·8	6083·2
7	12·5	2	25·0	156·3	312·60	1953·1	3906·2
8	13·2	4	52·8	174·2	696·80	2300·0	9200·0
9	13·6	2	27·2	185·0	370·00	2515·5	5031·0
10	13·95	4	55·8	194·6	778·40	2714·7	10868·8
11	14·05	2	28·1	197·4	394·80	2773·5	5547·0
12	14·15	4	56·6	200·0	800·00	2833·1	11332·4
13	14·25	2	28·5	203·0	406·00	2893·6	5787·2
14	14·25	4	57·0	203·0	812·00	2893·6	11574·4
15	14·25	2	28·5	203·0	406·00	2893·6	5787·2
16	14·25	4	57·0	203·0	812·00	2893·6	11574·4
17	14·2	2	28·4	201·6	403·20	2863·3	5726·6
18	14·15	4	56·6	200·2	800·80	2833·1	10332·4
19	14·05	2	28·1	197·4	394·80	2773·5	5547·0
20	13·95	4	55·8	194 6	778·40	2714·7	10858·8
21	13·9	2	27·8	193·2	386·40	2685·6	5371·2
22	13·7	4	54·8	187·7	750·80	2571·4	10285·6
23	13·5	2	27·0	182·3	364·60	2460·4	4920·8
24	13·3	4	53·2	176·9	707·60	2352·6	9410·4
25	13·05	2	26·1	170·3	340·60	2222·5	4445·0
26	12·75	4	51·0	162·6	650·40	2072·7	8290·8
27	12·4	2	24·8	150·8	307·60	1906·6	3813·2
28	11·9	4	47·6	141·6	566·40	1685·2	6740·8
29	11·05	2	22·1	122·1	244·20	1349·0	2698·0
30	9·8	4	39·2	96.0	384·00	941·2	3764·8
31	8·4	1	5·4	29.2	29·20	157·5	157·5
			1094·6		14067·70		174574·8

EMERSED.

No. of Ordinates.	Ordinates.	S.M.	Products.	Squares.	Products.	Cubes.	Products.
1	1·75	1	1·75	3·1	3·1	5·4	5·4
2	3·55	4	14·20	12·6	50·4	44·8	179·2
3	5·5	2	11·00	30·3	60·6	166·4	332·8
4	7·2	4	29·2	53·3	213·2	389·0	1556·0
5	9·0	2	18·0	81·0	162·0	729·0	1458·0
6	10·4	4	41·6	108·1	432·4	1124·9	4499·6
7	11·7	2	23·4	136·9	273·8	1601·6	3203·2
8	12·6	4	50·4	158·8	635·2	2376·0	9504·0
9	13·4	2	26·8	179·6	359·2	2406·1	4812·2
10	14·0	4	56·0	196·0	784·0	2744·0	10976·0
11	14·35	2	28·7	205·9	411·8	2955·0	5910·0
12	14·55	4	58·2	211·7	846·8	3080·3	12321·2
13	14·7	2	29·4	216·6	432·2	3176·5	6353·0
14	14·8	4	59·2	219·0	876·0	3241·8	12967·2
15	14·8	2	29·6	219·0	438·0	3241·8	6228·6
16	14·8	4	59·2	219·0	876·0	3241·8	12967·2
17	14·7	2	29·4	216·1	432·0	3176·5	6353·0
18	14·6	4	58·4	213·2	852·8	3112·2	12448·8
19	14·5	2	29·0	210·3	420·6	3048·6	6097·2
20	14·35	4	57·4	205·9	823·6	2955·0	11820·0
21	14·2	2	28·4	201·6	403·2	2863·3	5726·6
22	13·95	4	55·8	194·6	778·4	2714·7	10858·8
23	13·6	2	27·2	184·9	369·8	2515·5	5031·0
24	13·1	4	52·4	171·6	686·4	2248·0	8992·0
25	12·7	2	25·4	161·3	322·6	2048·3	4096·0
26	11·9	4	47·6	141·6	586·4	1685·2	6740·8
27	11·1	2	22·2	123·2	246·4	1367·7	2735·4
28	9·9	4	39·6	98·0	392·0	907·7	3630·8
29	8·4	2	16·8	70·6	141·2	592·7	1185·4
30	6·2	4	24·8	38·4	153·6	238·3	953·2
31	2·6	1	2·6	6·8	6·8	17·6	17·6
			1053·6		13490·5		180015·8
	Immersed ...		1094·6		14067·7		174574·8
	Area ...		2148·2 (*sum*)		577·7 (*difference*)		354590·6 (*sum*)

I have not given the work of finding the inclined water-line, because that involves no difficulty, nor have I given the work of finding the common metacentre. All the ordinary books contain examples of these.

The foregoing calculation gives us:—

$$\int Y_r^3\,dx + \int Y_l^3\,dx = 118196{\cdot}9$$

$$\int \tfrac{3}{2}\,Y_r^2\,dx - \int \tfrac{3}{2}\,Y_l^2\,dx = 288{\cdot}85$$

$$3\int Y_r\,dx + 3\int Y_l\,dx = 2148{\cdot}2$$

Hence, neglecting the interval, the moment which gives the inclined metacentre is one-third of

$$118196{\cdot}9 - \frac{(288{\cdot}85)^2}{2148{\cdot}2} \text{ or } 118158{\cdot}1$$

The interval was 12 feet; but the drawing was only to $\frac{1}{8}$th scale, while the measurements were read off on a $\frac{1}{4}$ scale. Hence this result must be multiplied by $\frac{1}{3} \times 12 \times (2)^3$, or 32. This makes the actual moment 378105·92 in (feet)^4. The displacement was 305,743 cubic feet. The metacentric height is therefore 12·37 for an inclination of 10°.

The calculation for the upright metacentre gave 12·23.

We have now to introduce the position of the centre of the weights, or centre of gravity of the vessel. In this case I shall assume it to be 4·6 feet below the common metacentre. We then have the following data for the calculation of the finite stability at 10°:—

$$\rho_1 - \rho_0 = 0{\cdot}14,\ \theta = 10°,\ \lambda = 4{\cdot}6$$

The calculation is then as follows:—

B. Stability for one metacentre:—

$$\begin{aligned} \log.\ \sin 10° &= 9{\cdot}23967 \\ \log.\ 4{\cdot}6 &= 0{\cdot}66276 \\ \log.\ 0{\cdot}7988 &= 9{\cdot}90243 \end{aligned}$$

C. Correction for second metacentre:—

$$\begin{aligned} \log.\ 0{\cdot}14 &= 9{\cdot}14613 \\ \log.\ \frac{2}{d} &= 2{\cdot}05915 \\ \log.\ \frac{1}{\theta} &= 9{\cdot} \\ & 0{\cdot}20528 = \log.\ 1{\cdot}6042 \\ \log.\ 0{\cdot}14 &= 9{\cdot}14613 \\ \log.\ \frac{2}{d^2} &= 3{\cdot}81728 \\ \log.\ \sin\theta &= 9{\cdot}23967 \\ \log.\ \frac{1}{\theta^2} &= 8{\cdot} \\ & 0{\cdot}20308 = \log.\ 1{\cdot}5961 \end{aligned}$$

Correction for second metacentre + 0·0081

D. The stability at 10° is therefore:—

Metacentric	0·7988 × D =	244227·5 (foot)⁴ =	6977·9 foot-tons
Correction	0·0081 × D =	2476·5 (foot)⁴ =	70·8 foot-tons
Actual stability	0·8069 × D =	246704·0 (foot)⁴ =	7048·7 foot-tons

The calculation of the dynamical stability is as follows:—

Metacentric.

log. λ	= 0·66276
log. versin 10°	= 8·18163
	8·84439
Dynamical stability (metacentric)	= 0·06989
Correction for second metacentre	= 0·00035
	0·07024

Correction.

log. $(\rho_1 - \rho_0)$	= 9·14613
log. $\frac{2}{d^2}$	= 3·81728
log. $\frac{1}{100}$	= 8·
log. versin 10°	= 8·18163
log. ·13965	= 9·14504
	0·13965
$\rho_1 - \rho_0$	= 0·14
	·00035

Hence the dynamical stability at 10° is:—

Metacentric	0·06989 × D =	21368 (foot)⁴ =	610·5 foot-tons
Correction	0·00035 × D =	107 (foot)⁴ =	3·0 foot-tons
	0·07024 × D =	21475 (foot)⁴ =	613·5 foot-tons

In order to find the elements of the curve, we have, as before,

log. $(\rho_1 - \rho_0)$ = log. 0·14 =		9·14613
log. $\frac{2}{d^2}$	=	3·81728
log. $\frac{1}{100}$	=	8·
log. r	= log. 9·192 =	0·96341

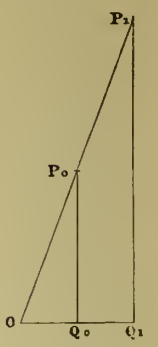
With this datum, and with $\rho_0 = 12{\cdot}23$, we can either calculate the stability for any other angle of inclination, or we can set it off geometrically.

APPENDIX V.

Geometrical Method of representing the Statical Stability of a Ship.

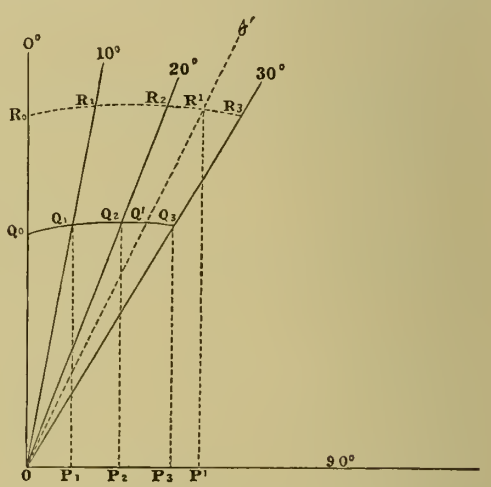
Reverting to the last two formulæ of Appendix III., it will be observed that the only part of the formula which varies with an alteration in the position of the weights, or of the centre of gravity, is λ, and that in the value of p, which belongs to the statical stability, this is associated with the factor sin θ. Hence, if we calculate $\frac{p}{\sin\theta}$ instead of p, for several inclinations, for any arbitrary position of the weights, and set

it off on a line making an angle $90 - \theta$ with a base line, we may lay off the change in the centre of weights along our sloping line, and its projection on the base line will represent the new p. Thus, if $< \mathrm{P\,O\,Q} = \theta$, and $\mathrm{O\,P_0}$ represents $\frac{p_0}{\sin \theta}$, and if the weight be raised from $\mathrm{P_0}$ to $\mathrm{P_1}$, then, while $\mathrm{O\,Q_0}$ represents p_0, $\mathrm{O\,Q_1}$ represents p_1. If the weights were lowered, $\mathrm{P_1}$ would simply be on the other side of $\mathrm{P_0}$.



Hence, if we can calculate the statical stability for one position of the weights and for several angles of inclination, we may exhibit by an easy geometrical method the statical leverage for any other angle (between the limits of accuracy), and for any other position of the weights, *provided the trim and displacement remain unaltered.*

For example; let $\mathrm{O\,P_1}$, $\mathrm{O\,P_2}$, $\mathrm{O\,P_3}$ represent the finite stabilities p_1, p_2, p_3 at angles of 10°, 20°, 30°, then $\mathrm{O\,Q}$ will stand for $\frac{p}{\sin \theta}$. We must lay off the curve $\mathrm{Q_0}$.....$\mathrm{Q_3}$ from calculated data, and then, if we want to find the statical stability for an angle θ', after the weights have been raised from Q to R, we have simply to draw the indefinite line $\mathrm{O}\,\theta'$ at an angle θ' with $\mathrm{O\,Q_0}$, set off from the calculated curve of Q, $\mathrm{Q'\,R'} = \mathrm{Q_0\,R_0}$, let fall the perpendicular $\mathrm{R'\,P'}$, and then $\mathrm{O\,P'}$ gives the leverage of stability for the altered circumstances. To get the actual stability we have to multiply by the displacement; but of course this is a mere matter of scale in reading off.



I do not enlarge upon this matter, because, in the first place, the geometry of it is exceedingly easy, and secondly, there is so little experience as yet of this class of work, that it is not easy to foresee what direction ought to be taken in its further developments.

A similar construction, but more complicated, will represent the variation in the dynamical stability. At present, however, this is of no practical interest.

DISCUSSION.

Mr. Scott Russell: I would merely venture to confirm what Mr. Merrifield has said, that hitherto it has been the custom to take a ship and say "this is her load-draught," to make all the calculations of the qualities of the ship on that load-draught and to consider that the exhaustion of the subject. After the discussion on the term "draught of water," and so on, which we have had in this room, I need hardly tell you that what Mr. Merrifield has said is most true, that a ship is not one ship, but that she is

many ships; that she is a different ship at every different draught of water, that the calculations become extremely difficult for the ship in all her positions and at all her draughts, and therefore the investigations of Mr. Merrifield, as simplifying the whole of that, and getting it both into the mind and out at the fingers' ends most compendiously, will, I have no doubt, be found of very great value in this new and comparatively unbroken field of research.

The CHAIRMAN: Did you say yesterday, Mr. Barnaby, that your experiments on stability had been proved by this system of Mr. Merrifield's? Did you say that the students did calculate the stability at the School of Naval Architecture?

Mr. BARNABY: I find that what I said yesterday was not quite understood; and, therefore, I will repeat it now. I had an instrument here yesterday—it is taken away now—which was simply two pendulums, one being 14 feet 4 inches long, and the other being 22 feet long. Those two pendulums vibrated in the same time as the ship which had been experimented on. The third pendulum was the same as the time in which the ship oscillated. When the weight was raised 20 feet the mean time of the oscillation corresponded with that of the longer pendulum. These two pendulums were provided simply for this purpose. It might have been said by persons "the differences you are pointing out to us "between the times of the oscillation of the ship you are experimenting on are so delicate, so minute, that "I do not believe you could see the difference." In order, then, to make that point clear I brought two pendulums. I could not bring the ship and shew her rolling that you might see it for yourselves, but I could bring two pendulums which had the same time. I then said that these two pendulums when at South Kensington were set vibrating, and that the students were then asked, not knowing the times which the ship oscillated, to say what the times were, counting the pendulums with their watches, and they gave the times for three experiments accurately.

The CHAIRMAN: As observers?

Mr. BARNABY: As observers.

The discussion on this subject here dropped, but was resumed later in the day.

Mr. BARNES: I was going to speak in the Discussion on Mr. Merrifield's other Paper, and as Mr. Merrifield has mentioned my name, I will, if I may be allowed two or three words, shew wherein he and I agree, and wherein we differ. Now, I would mention, that what is generally done, and readily done, by naval architects, is to find the metacentre—the distance between the centre of buoyancy and the metacentre. Permit me to say, that I think if naval architects would thoroughly examine and ascertain what becomes of the centre of buoyancy when a ship is inclined from the upright position, supposing the vertical line drawn through it always to pass through the metacentre, they would find that calculation both ample and sufficient for all purposes of comparison in all ordinary ships or ships of the usual form. What is required in addition to this is, to give the naval architect such experience in calculation that he may know where the metacentric rule would apply and where it would fail. It has been shown, years ago, by Mr. Atwood, in his valuable Papers, read before the Royal Society, that there are cases in which the metacentric method will not hold good. He has also shown how, in a general way, the actual stability of a ship may be found for all angles of inclination. There are also Papers in the *Transactions* of this Institution which go in the same direction, and which aim at rendering the calculations of the actual stability of a ship both accurate and simple. Among these Papers is one of my own, in which I think

that I have placed the question of calculating a ship's stability on the same footing as that of calculating displacement; the former being found by my method as accurately as displacement by the ordinary rule, and like that method according to the amount of accuracy required, with a greater or less amount of labour. Mr. Merrifield proposes to reduce the amount of labour of obtaining the stability in the following way. He first finds for a given inclination the position of the inclined plane of flotation, and then calculates its moment of inertia about a longitudinal axis passing through its centre of gravity; then by dividing, in the usual way in finding the metacentre, two thirds of this moment by the displacement, the result will give the radius of curvature of the locus of the centres of buoyancy corresponding to the given inclined water-line. Now this is all that Mr. Merrifield attempts to calculate. He knows nothing of the position of the centre of buoyancy itself in the inclined position; he does not know what becomes of the centre of buoyancy after the ship leaves the upright position. The form of the ship may vary in many ways between the upright and inclined water-lines, thereby causing corresponding variations in the position of the centre of buoyancy in the inclined position, and consequently also in the stability of the ship at the given inclination, in spite of the moment of inertia of the inclined plane of flotation, and therefore of the corresponding radius of curvature, remaining the same. My method of calculating the stability of a ship takes into account all variations, between the upright and inclined water-lines, whereas Mr. Merrifield's does not. Now I think the main object in calculating the stability of a ship should be to give accuracy to the ideas of the naval architect as to what becomes of the centre of buoyancy of a ship when she is inclined at certain given angles; and after he has gained some experience he will find it unnecessary, except in special cases, to go further than to calculate the height of the metacentre. While I am of opinion, therefore, that Mr. Merrifield's Paper is very interesting and very ingenious, I do not consider that it will prove of much practical importance. The way in which Mr. Merrifield finds the position of the inclined water-line is a very good one and very ingenious. I believe, however, that after having by that method fixed the position of the inclined line, the volume of the *ins* and *outs* would, on calculating, be found to vary, and that it would still be necessary to apply the usual corrections for a new inclined water-line.

Mr. Merrifield: I would make an observation or two in reply to what Mr. Barnes has said; and in the first place, I would say how thankful I am to him for his criticism of me, for I should regret nothing more, than to think that any person, who was so well acquainted with the method as Mr. Barnes, should take it merely on my credit. I want everybody to understand the points in which my method fails, as well as those in which it succeeds. I do not think I go with him to the extreme length as to the rapidity of the calculations, because I think this:—It is very true if Mr. Barnes had to design any vessel of the *Bellerophon* or the *Warrior* class, he is so thoroughly familiar with it, that he could probably say within a foot where the centre of gravity would be, without the trouble of calculating it; but that is not the case with the greater part of designers. It appeared to me thus:—that the calculation of the stability was practically so difficult, that it would never be done at all in any ordinary Yard. We know as a matter of fact that it has not been done—at least I do not understand that it has been done—for more than six or eight of Her Majesty's recent ships—calculating the stability by finite angles.

Mr. Reed: Do you mean by experiment?

Mr. Merrifield: No, theoretically; it has been done in a few instances only. My method does save more than half the work, and does make it practicable. In the next place, I find the correction by

my method in a great many ships, though not very large, is still sensible. As to there being any other correction necessary, the first correction was so small, that it is likely the second correction would be insignificant. With regard to my only taking extremes, that is true as far as the final calculation is concerned; but it can scarcely be said to be absolutely true throughout the process, because the first operation I have to do is to find the inclined water-line, and you will find that it is no such easy task to find a line that shall give you the same displacement. I quite admit that in a *Monitor* or with overhanging sides, the thing is so discontinuous, that my method fails and does not apply; but I claim for my method, that it gives us the calculations with a very moderate amount of trouble. I think I have said all I have to say. I agree with nearly all that Mr. Barnes has said, but I hope my calculation is not without value.

[Mr. RAWSON then made some remarks on the value of the method proposed by Mr. Merrifield. The Discussion which ensued was of a very technical character, and ultimately Mr. Rawson was requested to favour the Institution with a Note embodying his views on the subject. His remarks are appended.]

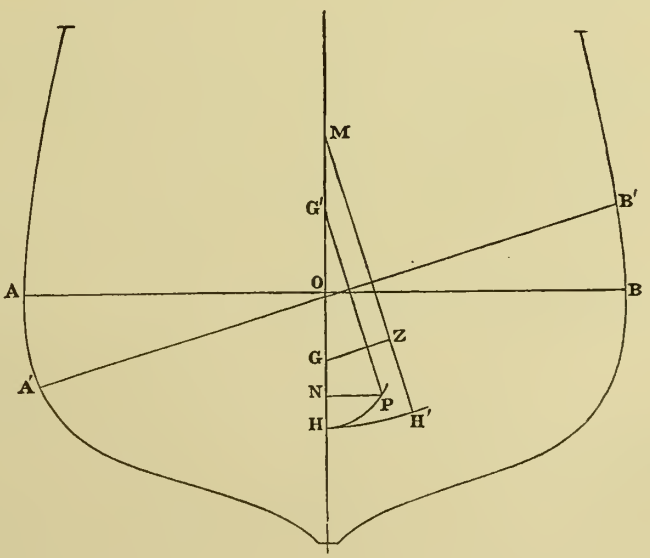
REMARKS

On Mr. MERRIFIELD'S *Method of Calculating the Finite Stability of Ships, by* ROBERT RAWSON, *Esq., Assoc. I.N.A., Hon. Member of the Literary and Philosophic Society, Manchester.*

Let H H′, in the woodcut, be the locus of the centre of buoyancy as the ship heels from the upright position A B to the inclined position A′ B′. The known properties of this curve, which is called the *metacentric involute*, are that the normals at H and H′ are perpendicular to the water-lines A B and A′ B′ respectively. If θ be put for the angle of inclination of A B to A′ B′, then

$$\text{The stability of the vessel} = \frac{\text{G Z} \cdot \text{W}}{\sin \theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where W is the weight of vessel, G the centre of gravity of the vessel, and G Z the perpendicular to the normal H′ M. (See *Euler on Vessels*, page 23).



Now, Mr. Merrifield's object, which is highly interesting to the scientific Naval Architect, is to adapt a conic, the properties of which are well known, to represent the *metacentric involute* H H′, the exact position of which depends on the outer form of the vessel; and, therefore, its properties are not sufficiently known to enable the Naval Architect to obtain a general relation, easy of application, between the stability of a ship and the angle through which it is inclined.

The conic which Mr. Merrifield proposes, and from which he derives an approximate formula for the stability at any finite angle, is an ellipse, whose centre is on the line H O, and whose vertex is at H.

Let H P be any portion of this ellipse, where the normal P G′ is parallel to H′ M, and let y, x be the co-ordinates of P, the origin being at the centre of the ellipse, then the equation to the ellipse will be:—

$$\frac{y^2}{a^2\,(1-e^2)} + \frac{x^2}{a^2} = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where (a) and (e) are well-known quantities, and may be regarded as *variable parameters.*

By giving various values to these *parameters*, there will be various corresponding ellipses, of the form denoted by equation (2), which will approximate, more or less, to the true position of the *metacentric involute* H H′. The best values, therefore, of (a) and (e) are evidently those which bring the two curves, *viz.*, the approximating ellipse and the *metacentric involute*, into the closest possible proximity with each other.

Mr. Merrifield has proposed to determine (a) and (e), from the conditions that the radii of curvature of the *metacentric involute* H H′ at the points H and H′ shall be respectively equal to the radii of curvature of the approximating ellipse at the points H and P. From these conditions, and from the known properties of the approximating ellipse, Mr. Merrifield has obtained a formula for the stability of a ship at any given angle of inclination. Of this method it may be observed that the values of (a) and (e) fail to insure the coincidence either of the approximating ellipse with the metacentric involute at the point H′, or of the normals P G′ with the normal H′ M. The reason of this is evident, from the consideration that there are three conditions to be fulfilled to insure this coincidence, *viz.*, the lengths of the radii of curvature at H and H′, together with the position of H′. These three conditions cannot be satisfied generally by means of the two parameters (a) and (e).

While adding my testimony to the value of Mr. Merrifield's investigation of this subject, I propose, in what follows, to determine the parameters (a) and (e) in a manner slightly different from that which he has adopted.

This method consists in determining the two arbitrary parameters (a) and (e) in equation (2), so that the stability at H and H′, on the *metacentric involute* H H′, shall be respectively equal to the stability of the approximating ellipse H P at the points H and P.

Let θ = angle which P G′ makes with H O. (From *Hymer's Conics*, page 80).

$$\text{P G}' = \frac{a\,(1-e^2)}{\sqrt{1-e^2\sin^2\theta}}$$

Draw P N perpendicular to H O,

$$\therefore \text{N G}' = \frac{a\,(1-e^2)\cos\theta}{\sqrt{1-e^2\sin^2\theta}}$$

$$\text{And H N} = a - \frac{a\cos\theta}{\sqrt{1-e^2\sin^2\theta}}$$

Therefore,

$$\text{H G}' = a - \frac{a\,e^2\cos\theta}{\sqrt{1-e^2\sin^2\theta}}$$

Now, if H G be denoted by h, there results :—

$$G\,G' = a - h - \frac{a\,e^2 \cos\theta}{\sqrt{1 - e^2 \sin^2\theta}}$$

From this value and equation (1) we obtain

(A).....$\left\{ a - h - \frac{a\,e^2 \cos\theta}{\sqrt{1 - e^2 \sin^2\theta}} \right\}$ W = the stability, at an angle θ, calculated from the approximating ellipse, where W equals the weight of the vessel.

The expression (A) contains (a) and (e), the variable parameters, and it is proposed here to determine them by assuming S_1 W, S_2 W to represent the stabilities calculated from the true *metacentric involute* H H′ at the angles (zero) and (α) respectively.

From (A) we have

$$S_1 = a\,(1 - e^2) - h \quad \text{.....(3)}$$

$$S_2 = a - h - \frac{a\,e^2 \cos\alpha}{\sqrt{1 - e^2 \sin^2\alpha}} \quad \text{.....(4)}$$

From the equations (3) and (4), by the help of (A), the stability, at any angle θ, may be calculated approximately.

ON THE PRACTICAL APPLICATION OF DR. WOOLLEY'S RULE TO THE USUAL CALCULATIONS OF A SHIP.*

By Charles W. Merrifield, F.R.S., Hon. Secretary and Assoc., I.N.A.

[Read at the Eighth Session of the Institution of Naval Architects, April 13th, 1867; Joseph H. Ritchie, Esq., Mem. Council, in the Chair.]

I am of opinion that Dr. Woolley's Rule has not hitherto been appreciated to anything like the extent it deserves. It offers by far the easiest mode of obtaining not only the displacement, but also the centre of gravity of a ship, and it does this with less than half the labour attending the usual application of Simpson's First Rule, while it affords exactly the same verification. As to accuracy, it is theoretically quite as satisfactory as Simpson's, and only differs from it by a quantity far within the necessary limits of error in measurement. In practice, the difference is found to be inappreciable. In the example subjoined to this Paper, the result obtained for the displacement only differs by one in 4,000 from Chapman's result, and, for the moment in length, by one in 5,000.

Believing, as I still do, that it was only from its not being presented in a practical form for direct use, that it had not been generally adopted, I have bestowed much thought and trouble in producing a scheme which I think leaves but little room for improvement. I regret to say that I have only the claim of prior publication, not of invention, for I find that Mr. Crossland, Assistant-Constructor of the Navy, had, years ago, calculated the quantities of the *Hector* in an exactly similar scheme, and sent it privately to Dr. Woolley. I do not feel that I can quite easily forgive my friend Mr. Crossland for not having published it himself at the time, thus saving me my present task, with all the trouble it has cost me to re-invent it, and sparing much calculation to naval architects. Mr. Crossland's Paper has been mislaid, but further search will be made for it, and if it can be found, it will be added as a further example.

It appears to me that the chief advantage of Dr. Woolley's Rule is to the designer of ships. It offers by far the readiest method of finding the displacement and centre of gravity; but it is not adapted for giving either a mean section or a scale of displacement.

* Received 10th April, 1867.

It is, therefore, not adapted for the final calculation of a ship. That is best done by the ordinary application of Simpson's First Rule, arranged on the Admiralty plan. This will be found set out in page 46 of *Shipbuilding, Theoretical and Practical*, by Watts, Napier, Rankine, and Barnes. (Mc Kenzie and Co.)

The quickest way of obtaining a displacement is to apply Dr. Woolley's Rule geometrically to the half-breadth plan, by marking his multipliers in pencil on this plan, and running them off on a long slip of straight-edged paper. I add the detail of this method also as an Appendix. It is reprinted from the *Mechanics' Magazine.*

I refer to Vol. VI. of our *Transactions*, (1865), page 40, for a theoretical account of Dr. Woolley's Rule. The present Paper is intended to be confined to its application to practical work.

It will be as well first to recall the principal statement of it, which is thus:

Let us take a block of nine ordinates, or half-breadths of the ship, and call them

$$a_1, b_1, c_1,$$
$$a_2, b_2, c_2,$$
$$a_3, b_3, c_3,$$

then the volume of the whole block is

$$\tfrac{2}{3} h k (a_2 + b_1 + 2 b_2 + b_3 + c_2),$$

h and k being the horizontal and vertical intervals. It will be observed that the corner ordinates—a_1 c_1 c_3 a_3—do not appear in the result. We may write the rule more conveniently in the following form—

$$\tfrac{2}{3} h k \begin{Bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{Bmatrix}$$

it being understood that the numbers in $\begin{Bmatrix} \\ \\ \end{Bmatrix}$ are multipliers, like Simpson's, which have to be associated with proper ordinates. In Simpson's First Rule, the fundamental set of multipliers is 1, 4, 1, and they are combined as follows:—

$$\begin{array}{r} 1\ 4\ 1 \\ \quad 1\ 4\ 1 \\ \quad\quad 1\ 4\ 1 \\ \quad\quad\quad 1\ 4\ 1, \text{ \&c.} \\ \hline 1\ 4\ 2\ 4\ 2\ 4\ 2\ 4\ 1 \end{array}$$

each set overlapping on the common ordinate, which is doubled in consequence. The same thing happens with Dr. Woolley's multipliers. The following group,

$$\begin{Bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{Bmatrix} + \begin{Bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{Bmatrix} + \begin{Bmatrix} 0 & 1 & 0 \\ 1 & 2 & 1 \\ 0 & 1 & 0 \end{Bmatrix}$$

$$\begin{Bmatrix} 0&1&0 \\ 1&2&1 \\ 0&1&0 \end{Bmatrix} + \begin{Bmatrix} 0&1&0 \\ 1&2&1 \\ 0&1&0 \end{Bmatrix} + \begin{Bmatrix} 0&1&0 \\ 1&2&1 \\ 0&1&0 \end{Bmatrix}$$

$$\text{becomes } \begin{Bmatrix} 0&1&0&1&0&1&0 \\ 1&2&2&2&2&2&1 \\ 0&2&0&2&0&2&0 \\ 1&2&2&2&2&2&1 \\ 0&1&0&1&0&1&0 \end{Bmatrix}$$

which has still to be multiplied by $\frac{2}{3}\,h\,k$, or two-thirds of the product of the intervals. Taking a large number of ordinates, the multipliers run

	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0
1	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1
	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	

I wish particularly to draw attention to the *bordered* character of the scheme. It will be observed that the multipliers along the border are all unity, and that those in the middle are all 2, zero alone occurring throughout the scheme.

If we neglect *parts supposed* or *appendages*, and work on a fair scheme, we may introduce the multipliers for moments at the end of the process, just as we do in getting out the displacement calculation by the common Admiralty calculation. That is to say, we get in the ordinates with their proper multipliers 0, 1, and 2, in a square scheme, and add, horizontally and vertically. The cross additions agree for the displacement, thus verifying each other, and the moments are obtained by bringing in the multipliers 0, 1, 2, 3, 4, &c., to the horizontal sums for the moment in length, and to the vertical summation for the moment in depth or height.

The accompanying example will shew that the work is easily done, in practice. The zeros or cyphers are got into the schedule at once. The *border* ordinates are got in with a scale the same as that of the drawing, and the inside ordinates to half-scale, so as to read them off double. That is, if the drawing be of the usual scale of a quarter-inch to the foot, we read off the border ordinates with a quarter-inch scale, and the inside ordinates into an eighth scale. The rest of the work will be gathered from an example.

I subjoin to this Paper, by way of further Appendix, a formal proof that the moments are obtained in proper form by the process used. It is re-printed from the *Mechanics' Magazine* for 1866.

The example which I give is taken from Dr. Chapman (Inman's edition, pp. 5-15). I have neglected all appendages, because I think they would only confuse the reader, and after all, they must always be dealt with independently.

There is no theoretical difficulty in applying Dr. Woolley's Rule to the use of intermediate ordinates, either for the floor or the cant bodies; but then it becomes complicated, and thus loses its advantage over the ordinary rule. For that reason I do not exemplify it.

APPENDIX I.

Example of the Application of Dr. Woolley's Rule to the Calculation of the Displacement and Centre of Buoyancy of the same Ship as that calculated by Chapman in his Architectura Navalis Mercatoria, *Inman's Edition, pp.* 5-15, *and figures* 43, 44, 46. *Horizontal Interval,* 6·27 *feet; Vertical Interval,* 1·62 *feet.*

Transverse Sections. No.	Frames.	W.L. 1	W.L. 2	W.L. 3	W.L. 4	W.L. 5	W.L. 6	W.L. 7	Sums.	Multrs. for moments.	Products for moments.
1	27	0	2·16	0	0·86	0	0·45	0	3·47	0	
2	24	8·88	12·32	7·20	4·36	2·94	1·94	0·67	38·31	1	38·31
3	21	0	18·28	0	8·04	0	2·96	0	29·28	2	58·56
4	18	12·46	22·00	17·80	12·48	7·62	4·22	1·10	77·68	3	233·04
5	15	0	24·72	0	16·74	0	5·96	0	47·42	4	189·68
6	12	13·91	26·38	23·96	20·20	14·66	8·52	1·78	109·41	5	547·05
7	9	0	27·62	0	22·60	0	11·50	0	61·72	6	370·32
8	6	14·61	28·36	26·60	24·02	20·08	14·00	2·63	130·30	7	912·10
9	3	0	28·78	0	24·80	0	15·80	0	69·38	8	555·04
10	O	14·80	28·80	27·34	24·96	21·56	16·10	3·00	136·56	9	1229·04
11	C	0	28·72	0	24·60	0	15·44	0	68·76	10	687·60
12	F	14·57	28·12	26·34	23·60	19·62	13·50	2·40	128·15	11	1409·65
13	I	0	27·10	0	21·62	0	10·76	0	59·48	12	713·76
14	M	13·43	25·16	22·28	18·30	13·44	7·76	1·57	101·94	13	1325·22
15	P	0	21·64	0	13·66	0	5·06	0	40·36	14	565·04
16	S	9·49	15·60	11·94	8·20	5·36	3·10	0·77	54·46	15	816·90
17	W	0	3·73	0	1·70	0	0·60	0	6·03	16	96.48
Sums		102·15	369·49	163·46	270·74	105·28	137·67	13·92	1162·71	M	9747·79
Multrs. for moments		0	1	2	3	4	5	6			
Products for moments			369·49	326·92	812·22	421.12	688·35	83·52	2701·62		

Displacement.	Centre of Buoyancy in length.	Centre of Buoyancy in depth from L.W.L.
1162·71	116271) 974779 (8·3837	116271) 270162 (2·3236
$\frac{2}{3}$ H. I. 4·18	930168	232542
930168	44611	37620
116271	34881	34881
465084	9730	2739
4860·1278	9302	2325
V. I. 1·62	428	414
97202556	349	349
291607668	79	65
48601278		
7873·407036	8·3837	2·3236
2	H.I. 6·27	V. I. 1·62
5) 15746·8 cubic feet	58·6859	4·6472
	16·7674	1·39416
7) 3149·4	50·3022	2·3236
449·9 tons.	52·565799	3·764232

Displacement	...	...	15746·8 cubic feet, or 449·9 tons.
Centre of Buoyancy	...	...	52·5658 feet forward of frame 27.
,, ,,	...	...	3·7642 feet below L.W.L.

NOTE.—No account is taken of the appendages in this calculation. Allowing for these, I find that the figures above obtained differ by less than 1 in 4,000 from the corresponding results given by Chapman.

APPENDIX II.

Formal Instructions for the Calculation of Displacement, or Capacity, and Position of Centre of Gravity by Dr. Woolley's Rule.

The calculator will first count the transverse sections and horizontal sections which he intends to use, taking care to use an odd number of them both ways, as in the ordinary rule.

He will then mark out on the scheme his first and last transverse sections, and his first and last horizontal sections, as a border. The object of this is only to assist the eye, and prevent error. Any effectual marking, or even careful attention without marking, will answer the purpose.

Cyphers should then be written in the squares which are odd, both in column and line. These may of course be printed in the scheme, if thought proper.

Then, assuming the drawing, from which the calculation is to be made, to be on a scale of one quarter of an inch to the foot, the calculator will take a $\frac{1}{4}$-inch scale, and get in the half breadths on his coloured border, that is, on his first and last transverse sections, and his first and last horizontal sections.

He will then take a scale of an eighth of an inch to the foot, and get in all the intermediate half breadths, which will thus be doubled.

In both cases he will omit all those in which a zero is already entered in the scheme—that is to say, those which are odd in both sets of sections.

The figures are then to be added along and across, and carefully balanced, and then the moments got.

The displacement of one half the ship will be got by multiplying the gross total by two-thirds of the product of the intervals.

The moments will take the same multiplier, and besides that, the interval again, one way or the other, whichever the moment be taken.

APPENDIX III.

Draught of Printed Scheme for Calculation of Displacement and Centre of Buoyancy by Dr. Woolley's Rule.

Name of Ship_____

Transverse Sections. No.	W. L. No.	W. L. No.	W. L. No.	[*Continue.*]	W. L. No.	Sums.	Multipliers for Moments.	Products for Moments.	Metacentre. Half-breadths on L. W. L.	Cubes.	S. M.	Products.
											1	
											4	
											2	
											4	
											&c.	
		[*Continue.*]							[*Continue.*]			
Sums.									Total			
Multrs.				[*Continue.*]			Horizontal Interval			Feet.		
Products for Moments							Vertical Interval			Feet.		

Displacement.	Centre of Buoyancy in Length.	Centre of Buoyancy in Depth.	Metacentre.

APPENDIX IV.

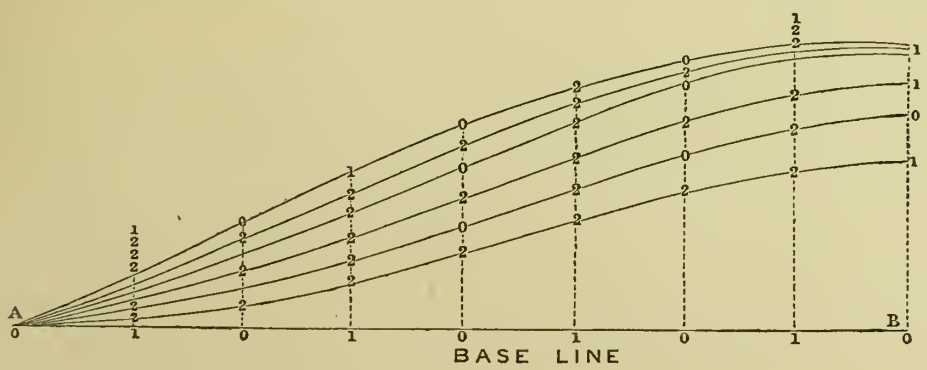
On a rapid Geometrical Method of finding a Ship's Displacement from the Drawings, by an application of Dr. Woolley's Rule, by CHARLES W. MERRIFIELD, F.R.S.

(Extracted from the *Mechanics' Magazine* for November 17, 1865.)

It has occurred to me that by combining Dr. Woolley's Rule with actual measurement, and by effecting such an arrangement of the process as to entirely obviate all confusion, it would be possible to obtain the very desirable object of getting out a displacement by a few minutes' work, with a very fair degree of approximation. I have succeeded in devising a simple arrangement, which answers the purpose admirably, where the drawings are so arranged as to be ready for the ordinary process of calculation. My only claim of novelty is for the practical arrangement and combination of the processes. No one step is new, except, perhaps, that of writing down the multipliers on the draught. Dr. Woolley's Rule may be thus stated:—If we take a set of ordinates arranged in a rectangle containing an odd number each way (say 9 × 7), and affect them with the following multipliers, of which the law is easily seen:—

0	1	0	1	0	1	0	1	0
1	2	2	2	2	2	2	2	1
0	2	2	2	0	2	0	2	0
1	2	2	2	2	2	2	2	1
0	2	2	2	0	2	0	2	0
1	2	2	2	2	2	2	2	1
0	1	0	1	0	1	0	1	0

then the volume is the sum of the ordinates so multiplied, and also multiplied by two-thirds of the product of the intervals between the ordinates one way and the other. Now, let us suppose we have either got the planking into the half-breadth plan, or else that we want the moulded capacity, and let us mark the intersections with Woolley's multipliers as in the subjoined sketch, which is supposed to represent the after-body of



which the displacement is required. These numbers may be written on the draft in pencil without injuring it. Where the multipliers get too crowded by the level lines coming close together, they may be written over the L.W.L.

Next, take a long slip of drawing paper, with a clean edge, and a sharp hard pencil, and measure off upon it every ordinate which has a number at the head of it in the plan, *taking twice those marked* 2, and neglecting those marked zero. Each measurement is to begin on the strip where the previous one ends, so that the whole length on the strip will represent the sum of the ordinates with their proper multipliers. The measurements are got by actually applying the strip of paper to the ordinates. A strip of moderate length will do if the repeated markings have a distinguishing sign. It only remains to multiply the total length of the strip (to scale) successively by two-thirds, by the length interval, and by the depth interval, and then we have the displacement in feet. The process is very much easier to follow than to describe, and the result is quite as accurate as the measurements on the draft. The draft requires to be a *fair* one, with all the intervals equidistant, and an odd number of ordinates each way. If this be the case, the displacement may be got out in a few minutes. If there be any eccentricities of form or arrangement, these must be dealt with separately, as in ordinary work. I have satisfied myself upon trial that the process is most satisfactory, as far as quickness is concerned; Dr. Woolley's Rule is too well understood to leave any doubt as to accuracy.

APPENDIX V.

Formal Proof of the Extension of Dr. Woolley's Rule to the Integration of Moments, by CHARLES W. MERRIFIELD, F.R.S.

(Extracted from the *Mechanics' Magazine* for December 21, 1866.)

I have succeeded in extending Dr. Woolley's Rule to the integration for moments. The resulting rule is very remarkable for its simplicity; but further experience is required to shew whether it is anything more than an analytical curiosity. The fundamental principle is to divide the solid to be measured into rectangular blocks, of which one side only (say the top) is bounded by a curved surface, which is assumed to be a paraboloid with its axis vertical.

Let the equation to the surface be

$$z = \phi(x, y) = a + bx + cy + dx^2 + ey^2 + fxy.$$

Then, if we integrate from $-h$ to $+h$, with regard to x, and from $-k$ to $+k$, with regard to y, we have:

$$V = \iint z\,dx\,dy = \tfrac{2}{3}hk\,(6a + 2dh^2 + 2ek^2)$$
$$= \tfrac{2}{3}hk\{\phi(-h, 0) + \phi(0, -k) + 2\phi(0, 0) + \phi(0, k) + \phi(h, 0)\}.$$

Now, if we look simply to the numerical multipliers of the ordinates ϕ to (0, 0) &c., we see that, for each block of nine ordinates, they run

0	1	0			0	1	0	1	0
1	2	1	or, for 15 ordinates,		1	2	2	2	1
0	1	0			0	1	0	1	0

and the law is seen to be very easy. This constitutes Dr. Woolley's Rule in its simplest form. It may be remarked that the rule holds if we make the equation of the surface contain the terms

$$a x^3 + \beta x^2 y + \gamma xy^2 + \delta y^3;$$

because these disappear in the double integration between equal and opposite limits. But in what follows these terms cannot be included.

For the moment about the plane of yz, we have to integrate $\iint xz\,dx\,dy$ between the same limits as before. We get

$$xz = ax + bx^2 + cxy + dx^3 + exy^2 + fx^2y.$$
$$\int_{-h}^{+h} dx \,.\, xz = \tfrac{2}{3}bh^3 + \tfrac{2}{3}fh^3y.$$
$$\int_{-k}^{+k} dy \int_{-h}^{+h} dx \,.\, xz = \tfrac{4}{3}bh^3k.$$

Now $\phi(h, 0) = a + bh + dh^2$

$\phi(-h, 0) = a - bh + dh^2$

Therefore $bh = \tfrac{1}{2}\phi(h, 0), -\tfrac{1}{2}\phi(-h, 0)$, and

$$\int_{-k}^{+k} dy \int_{-h}^{+h} dx\, xz = \tfrac{2}{3}h^2k\{\phi(h, 0) - \phi(-h, 0)\}.$$

This is very simple as far as the moment of one block is concerned. If we consider a slice of the solid, consisting of a succession of these blocks, we have to transfer the moment from a plane passing through the middle of each to a parallel plane bounding the first of them. Calling these blocks by the suffix belonging to their central ordinate, we find that the centre of gravity of block (m) is $\frac{M_m}{V_m}$ distant from its middle plane, and, therefore, $mh + \frac{M}{V_m}$ distant from the plane of reference. Its moment about the plane of reference is, therefore, $mh\ V_m + M_m$. Now the central ordinates of the successive blocks are at distances h, $3h$, $5h$, $7h$. . . . &c., from the plane of reference. Hence the moment of the slice is

$$h\,V_1 + 3\,h\,V_3 + 5\,h\,V_5 + \ldots\ldots\ldots$$
$$+ M_1 + M_3 \quad + \quad M_5 + \ldots\ldots\ldots$$

But

$$M_1 = \tfrac{2}{3}\,h^2k\left\{\phi\,(2\,h,\,0) - \phi\,(0,\,0)\right\}$$

$$M_3 = \tfrac{2}{3}\,h^2k\left\{\phi\,(4\,h,\,0) - \phi\,(2\,h,\,0)\right\}$$

$$M_{2n-1} = \tfrac{2}{3}\,h^2k\left\{\phi\,(2\,nh,\,0) - \phi\,\overline{(2n-2.\,h,\,0)}\right\}$$

in which the terms destroy one another alternately. We thus get, for the whole moment of the slice,

$$h\,V_1 + 3\,h\,V_3 + 5h\,V_5 + 7\,h\,V_7 + \ldots\ldots\ldots$$
$$(2\,n-1)\,h\,V_{2n-1} + \tfrac{2}{3}\,h^2k\left\{\phi\,(2\,nh,\,0) - \phi\,(0,\,0)\right\}.$$

The last term is a unique term for each slice.

Reverting now to the numerical co-efficients included in the terms h V, we see that they run—

$$\begin{vmatrix} 0&1&0\\ 1&2&1\\ 0&1&0 \end{vmatrix} \quad +3\times \quad \begin{vmatrix} 0&1&0\\ 1&2&1\\ 0&1&0 \end{vmatrix} \quad +5\times \quad \begin{vmatrix} 0&1&0\\ 1&2&1\\ 0&1&0 \end{vmatrix} \quad +\ldots, \text{ or}$$

0, 1, 0, 3, 0, 5, 0, 7, 0
1, 2, 4, 6, 8, 10, 12, 14, 7
0, 1, 0, 3, 0, 5, 0, 7, 0

for a slice of 27 ordinates or 2 × 8 intervals.

0, 1, 0, 3, 0, 5, 0, 7, 0
1, 2, 4, 6, 8, 10, 12, 14, 7
0, 2, 0, 6, 0, 10, 0, 14, 0
1, 2, 4, 6, 8, 10, 12, 14, 7
0, 2, 0, 6, 0, 10, 0, 14, 0
1, 2, 4, 6, 8, 10, 12, 14, 7
0, 1, 0, 3, 0, 5, 0, 7, 0

for a volume of 6 × 8 intervals or 7 × 9 ordinates.

These numbers follow a very remarkable law, which it is not difficult to trace. The ordinates have to be taken with these multipliers, and the whole sum must be multiplied by $\frac{2}{3}\,h^2k$. Moreover, for each slice, we must take the difference between the extreme ordinates (first and last) on its middle line, and multiply by $\frac{2}{3}\,h^2k$. We must add the sum of these to the previous result, and we then get the moment of the whole solid about the plane of *yz*. We can perform this addition on the co-efficients themselves, so as to include it in the scheme, which then becomes (for the last example given above),

0, 1, 0, 3, 0, 5, 0, 7, 0
0, 2, 4, 6, 8, 10, 12, 14, 8
0, 2, 0, 6, 0, 10, 0, 14, 0
0, 2, 4, 6, 8, 10, 12, 14, 8
0, 2, 0, 6, 0, 10, 0, 14, 0
0, 2, 4, 6, 8, 10, 12, 14, 8
0, 1, 0, 3, 0, 5, 0, 7, 0

The moment about the plane of xz merely involves the interchange of h and k in what goes before.

The same rule would be obtained if we were to multiply each ordinate by its distance from the plane of reference, form a new surface with these new ordinates, and then apply Dr. Woolley's Rule to obtain its volume.

DISCUSSION.

Captain HENDERSON: Might I be allowed to make one remark? Twenty years ago I acted upon the same principle for calculating the displacement of a ship. At that time there was a committee appointed by the Government, I attended that committee, and showed them a very simple mode, much like that now proposed, except the use of ruled papers for forming curves of areas, by which all commanders at least, might teach themselves to calculate the displacement of a ship. I brought it before that committee, and described it to them. I recollect it took twenty-five minutes to calculate the displacement of the *Euphrates*, a 700-ton ship. I will not detain you except to say that I brought it, in 1852, before the Board of Trade. It is an arrangement much like that of Dr. Woolley's, except that calculations are made on paper ruled to a scale. I brought it before the Board of Trade from 1852 to 1856. I have not for many years taken much notice of it, but I am still carrying it on for my own calculations. It exactly meets those Rules, and I will send a copy of it to the Institution. The tonnage being bated on the mean of the external bulk and internal space.

Mr. MERRIFIELD: If it is published, will you kindly give me the name of the book?

Captain HENDERSON: About one hundred and fifty were printed but not published. It is exactly what I proposed eighteen years ago, as an old sailor. The other publication on the subject is by a scientific man, Dr. Woolley. I went to Newfoundland in H.M.S. *Bellerophon*, in 1814; we had on board a Dr. Reed, who was very fond of teaching the youngsters. We had a school in the admiral's cabin, and one day Sir R. Keats said that whoever passed the best examination should have a midshipman's rating. I was fortunate enough to win it, as Admiral Belcher knows, who was in the same ship. I went to India in 1816 as a mariner. I there studied and became a shipbuilder in 1826. In 1829, in India, I built the steamer *Forbes;* she is now in existence, a good ship. I then built a vessel called the *Waterwitch*, in 1830; she is now in existence in China. I returned to this country in 1837, and laid my plans before Lord William Bentinck, who requested me to give evidence before the House of Commons on that very subject. Whatever those plans were, I am still carrying them out. I wish to utilise my experience of forty years. I will send you a copy; we both have the same object.

Mr. BARNES: Allow me to say that I could not hear one word that Captain Henderson has said.

Captain HENDERSON: I may mention this. That committee which sat so long was discussing whether it should be internal measurement or external measurement. I said—take both, and my proposition, I think, amounted to this—they ought to take the mean of external bulk and internal space, the rules of which are described.

The CHAIRMAN: For tonnage it is no use.

Captain HENDERSON: For displacement it is; therefore I say take both, you may see what my rules are, I take the mean of the two.

The CHAIRMAN: The question of tonnage has been very satisfactorily decided by Moorsom's Rule.

Captain HENDERSON: Yes, but I suffered. I wanted both. My tables gave the internal space and the external bulk, and now, in ships built of wood or iron, you get the internal capacity distinct from the external.

Mr. BARNES: Permit me to say that Mr. Merrifield has shown us how readily the displacement of a ship may be found by Dr. Woolley's Rule. The same rule could also with advantage be used to find the internal capacity of a ship, and would therefore prove valuable to the Board of Trade surveyors. By means of Moorsom's Rule the internal capacity of a ship is found with a small amount of labour, but there is no doubt that by using Dr. Woolley's Rule, the labour may be abridged. I wish, therefore, to invite the attention of persons requiring to calculate the register tonnage of ships to Dr. Woolley's Rule, and to recommend its use.

ON THE TECHNICAL EDUCATION OF NAVAL ARCHITECTS IN ENGLAND.*

By John Scott Russell, Esq., F.R.S., Vice-President.

[Read at the Eighth Session of the Institution of Naval Architects, April 13th, 1867; Joseph H. Ritchie, Esq., Mem. Council, in the Chair.]

At the Annual Meeting of this Society in 1863, the state of technical education provided in England for the youthful members of the profession of naval architects and naval engineers was made the subject of a long and earnest discussion.

In summing up that discussion, our President, Sir John Pakington, who then occupied the chair, expressly stated that the conviction at which he had arrived on the subject under discussion, was, that in respect of this branch of professional education, England was not in the position in which she, above all countries in the world, ought to be. He further expressed his earnest hope that the Council would make it their duty to devise the best means of giving practical effect to the views that had been laid before them. He concluded by saying:—"Nothing would give me greater pleasure "than co-operating with the Council for this purpose in any manner which may be "in my power."

I need scarcely remind you, that with such encouragement, the Council earnestly set about considering what means they could adopt for the effectual discharge of so responsible a duty, as the training of the generation who are to follow us, and on whom it will depend, to a very material extent, whether the reputation and power of England, as a mercantile country and a naval nation, shall wax stronger or shall wane.

They had first to settle, what sort of education and training was best fitted to turn out the youth who has shown a natural talent and capacity for mechanical construction and invention, into the world of practical duty, with powers of work best developed, and furnished with the best instruments and methods to enable him to discharge, with efficiency and certainty, the responsible duties of naval construction.

* Received 13th April, 1867.

They had next to consider how that education could, in this country, so scantily furnished with establishments for technical instruction, be provided; whether as appendage to some university, some dockyard, or some scientific institution.

Thirdly, they had to take into consideration the sources from which the young naval architects might be most successfully drawn; and lastly, where the fittest persons could be found able to teach a subject, which hitherto could scarcely be said to exist in England, as a branch either of science or of practical education.

After long and anxious deliberation, a final meeting of the Council, at which Sir John Pakington presided, arrived at an outline of a course of education comprehending all the subjects which should constitute the training of a naval architect. They recommended a course of training to extend over three years. They recommended that the time of the student should be divided between the mastery of the principles, the science, the calculations, the geometry, the physics, and all that concerns the theory of naval construction on the one hand; and on the other hand, the training which is to be had in the workshop, the dockyard, and the engine factory, where alone the student can obtain the complete mastery over the dead matter with which he has to struggle and strive and which he must shape to his liking, and mould to please his eye, and fashion to fulfil his purpose and intention, and by real practical mechanical work comprehend his tools, master their ways, and know how to make this dead matter of every sort obey the will of the designer, the maker, and the user.

Thus they solved the difficulty on which much discussion is often wasted; whether a theoretical or practical education yields the better training for the work of life: they solved it as that question can only be solved. Practice is what you do yourself, and what you learn from doing it. Theory is what another man has done, or knows how to teach you to do. The man who thinks he has so much wisdom and knowledge of his own, that he needs none of other people's, need acquire no science and no theory; but the man who thinks modestly enough of himself, and highly enough of the arduous duties which the professional responsibilities of the future have in store for him, will not think that any knowledge he himself can acquire, by the hard work of his own hands and head, ought to deprive him of the help and use he may get from that which is called theory, but which is in fact only the accumulation of the knowledge and the experience, the successes and the blunders, the few ways of doing things right and the many ways of doing things wrong, which have been found out by those who have gone before him, and which in the methodised form which makes it intelligible and teachable, we call science, or theory.

Thus, then, it was determined that the best education for the naval architect is divided thus:—

During the inclement months of winter, when the days for work are short and liable to interruption, it is best that he should devote himself exclusively to those studies and occupations, which can best be conducted within the walls of a school, or in the halls of lecture; and that on the other hand, the long days and finer weather of summer can best be turned to account, by engaging in the active operations of the workshop, the dockyard, and the manufactory. By this wise plan, each winter the student is taught what to do, and each summer he practises how to do it; and while, during each summer, he sees a multitude of processes carried on, the reasons for which he cannot see, the purposes of which he cannot imagine, the following winter enables him to learn why the objects could not have been otherwise attained, and why another mode of procedure might have led to unsuccessful contrivances or dangerous results; and so the Council believe that they have made each half of the student's time during three years both the antidote and the supplement, the preliminary and the consummation of the other half. To the young naval architect, therefore, science and practice are not two, but one.

Thus the Council arrived at the satisfactory issue of knowing exactly what they wanted; and the next difficulty was to find the men who could give this training, and the places in which it could be given. But at last a complete list was drawn out, of all the subjects which were required to be taught in the whole course of three years' training; and opposite to each course was set the name of a man of science—a naval architect, an engineer, a shipbuilder, or a naval officer, known to have earned skill and reputation in that particular subject; and it was soon ascertained by careful personal enquiry, that scarcely any one of these practical men was unwilling to communicate his knowledge to the youth of his profession; and, with remarkable readiness, men engaged in large undertakings, and involved in practical and professional business, expressed their readiness to set aside some portion of their time for the interests of our Institution. Thus, another great difficulty was successfully overcome.

The next great difficulty was to find a home for the young colony of naval architects during the winter months. It was, at one time, a question whether London itself, or some of the outports, was the better site for a school of naval architecture; and the question admitted of serious consideration, in so far, that it was much easier to find buildings and accommodation out of the Metropolis than in it; and it was also agreed, that the presence of the students in a dockyard town or a shipping port, might be of advantage to their studies; but these material advantages were soon overruled by the

consideration, that it had already been decided that the summer should be passed in the dockyards or private yards, so that to pass the winter there had ceased to be necessary; and there remained this further consideration, that the Metropolis presented an overwhelming advantage, in the large range of choice it afforded among the men of science, the professors and teachers, whom it was most desirable to enlist in the service of the proposed Institution; and finally, we had the advantage of the experience of France, where after many trials, the schools of naval architecture had been removed from remote dockyards, and concentrated in a single central college in Paris.

Having decided on the expediency of planting the new Institution in the Metropolis, the next point was to obtain the necessary buildings. Fortunately it happened that at that moment a long range of buildings belonging to the Science and Art Department of the Government at South Kensington had just become vacant, and on the application of the Council, the chief director of that establishment, Mr. H. Cole, expressed his willingness not only to give them up the building, but to grant them every facility in his power, provided he could obtain the consent of the Committee of Council on Education. Your President undertook that negociation, and the consent of the Committee of Council on Education was obtained, Lord Granville being then its President, and Mr. Lowe its Vice-President.

There still remained the necessity of obtaining the necessary funds: it was the opinion of the Council that, as in France the department of the Admiralty had shown the example of providing a high class of education for the naval architects of the royal dockyards, it might be represented to our Admiralty that it would be to the interests of England that her rising race of naval architects should not be inferior in any part of their education to those in France. This Sir John Pakington undertook, and placed himself in communication with the Duke of Somerset and Lord Clarence Paget on the subject, and the result was that the Admiralty decided to assist the School by setting aside an annual grant destined to provide for the education of naval architects and engineers for the naval dockyards. The Council on Education further agreed that they would defray other expenses of the School; and to crown the whole it was settled that the large historical collection of naval models, then ill accommodated in Somerset House, should be transferred to the buildings at Kensington, and so at once furnish a valuable material adjunct to the new School.

Thus, then, within six months after the subject had first been entertained by the Council, the new Royal School of Naval Architecture was founded. It opened in November, 1864, with twenty students,—sixteen from the dockyards, and four from private building establishments. In its second session of 1865 the students had increased to thirty-seven,—twenty-four from Government dockyards, and thirteen from private

yards, including four students sent by the Russian Government; and in the third session, now about to close, there have been forty-four students—twenty-nine from the public dockyards and fifteen from private yards; including four Russian, one Norwegian, and a Dutch student. It is important to add, that the private students, who are English subjects, have been allowed the privilege of a practical course of study in the dockyards, during the summer, equally with the dockyard students.

As this young Institution has now completed a full course of instruction during its first period of three years, I thought it would not be unwelcome to the Council to hear from one of its members, as a practical shipbuilder and naval architect, some account of its progress and some opinion as to its usefulness, and its degree of success in fulfilling the objects which the Council had in view, when they took the preliminary steps towards its establishment. I have taken the duty upon myself, because I have been thrown in the way of obtaining a tolerably intimate acquaintance with the nature of the studies carried on at Kensington, the manner in which they are taught, and the progress which the pupils have made; and further, as I myself have had nothing to do with the course of instruction carried on, and have only given occasional lectures, in common with many members of this Society, when requested to do so, I can speak freely on the merits, in which I have no share. And I have been induced to bring this matter before you by this further consideration:—that my professional duties having during the last twelve months taken me a good deal on the Continent, I have had occasion to examine some of the large institutions founded by the different Governments for giving a special technical education, not to one branch alone, but to all the important professions, trades and occupations, which contribute to the power, prosperity and wealth of a country. I have been confirmed in the soundness of a conviction grounded on my own long observation and experience, that the education which will fit a man for efficient discharge of his special duties in life, is one of the most valuable investments which can be made, either of the moneys of a community or of the revenues of State. I have seen foreign states, with whose recent history and present condition I am personally acquainted, making, under the influence of a systematic technical education, rapid but not to me astonishing progress. I think I must almost say I am sorry to see that in many points some of those nations which were behind us, have by this wise means of forethought and preparation supplied many of their deficiencies, overtaken us in many points where we believed competition to be hopeless, and surpassed us in some of the fields which we thought most exclusively our own.

I was accordingly led on returning home to look around me, with a view of comparing the practical education for life in England, with that which I had seen in some other countries. I regret to say that in technical education we are utterly behind other

civilized nations. They have large colleges, now generally called Polytechnic Institutions, amply endowed by the State, for which fine and even palatial edifices have been constructed, possessing ample museums, laboratories and workshops, having from fifty to one hundred teachers and professors, comprising the most distinguished men in each country. In such an establishment I found five or six hundred young men from eighteen to twenty-three, highly educated in their training, and thoroughly practical in their views; and I may add that I have had occasion to employ some of these young men in practical business, to observe the career of some of those employed by friends, and I have recommended young men, who could not find the fitting education in England, to enter these foreign institutions, whence I have seen them return to take high and successful rank above their contemporaries in England, for whom neither the Government nor the people of the country had thought fit to provide equal privileges.

Returning from such an examination (dispiriting to an Englishman), I must confess that our own School of Naval Architecture afforded me much satisfaction. I saw there between forty and fifty young men, between the ages of eighteen and twenty-five, obtaining as good a course of theoretical instruction, undergoing as systematic professional training, as any I had seen on the Continent. I have examined their drawings and their designs, I have seen their examination papers and answers, and I have been allowed the pleasure of seeing the books in which they record the notes which they make, and the conclusions which they draw from their own work in the dockyards, and from the practical work which they there see going on all around them, and the result has been that I have been unable to resist the temptation to communicate to you the conviction thus brought home to me, that our young School of Naval Architecture is as successful, as hopeful, and as well calculated to be useful to the future of the profession as we could have hoped or anticipated, and I came from the examination with the feeling that it may but be the beginning of a more extensive course of technical education that may comprehend the other great practical professions of this country.

I now proceed to lay before you the actual constitution and working of the School of Naval Architecture as at present constituted.

The Buildings of the School.

The Royal School of Naval Architecture and Marine Engineering occupies a range of buildings at South Kensington, affording the following accommodation:—

1*st.*—A large Lecture Hall.

2*nd.*—Three large Rooms for Drawing and Study.

3*rd.*—A Chemical Laboratory.

4*th.*—A Library.

5*th.*—Adjacent to it the Museum of Naval Models.

6*th.*—Also adjacent the Museum of Mechanical Inventions and Patents.

On these buildings I would remark, that, although they are large enough for the School in its present condition, it seems likely that in the future they would want considerable extension, that the addition of a large collection of marine engines, models and drawings, together with workshops in which the students might employ their leisure, and experimental rooms, and in which courses of experiments might be carried on, on the strength of different kinds of materials, and the value of different forms and proportions for strength, toughness and durability—and in which experiments on the friction of surfaces, properties of steam, and all the collateral branches of shipbuilding and engineering knowledge, might be conducted with the aid and instrumentality of the students themselves. And I may add, that I have seen in some of the technical schools abroad courses of practical study most advantageously followed out by students who had passed through the curriculum, and who were allowed the privilege, and sometimes paid for the duty, of continuing and extending their researches by means of private study and experiment beyond the curriculum of the School.

Constitution and Executive of the School.

The School has the advantage of being under the superintendence of a Member of your Council (Dr. Woolley), whose labours in the earlier School of Naval Architecture, which was extinguished in 1853, are so well known to the profession, and so gratefully acknowledged by his distinguished pupils; he is Inspector-General and Director of studies.

Mr. Merrifield is Principal. Of him, in his presence, I will say nothing, except that he has the interests of the School and the pupils deeply at heart, and performs his duties with unflagging zeal and energy. He had the assistance of Mr. Purkiss, of Trinity College, Cambridge, as his Vice-Principal; and since his lamented death that gentleman has been succeeded by Mr. H. M. Taylor, a fellow of the same college. Mr. Baskcomb, of one of the Royal Dockyards, as an instructor in naval drawing, and Mr. Maxton in engineering drawing, if judged by the works of their pupils, may be congratulated on the success with which they labour. The School has also been fortunate enough to secure the services of Mr. Cotterill as teacher of the theoretical part of engineering.

[Present

Present Constitution of the School.

SCIENCE AND ART DEPARTMENT.

COMMITTEE OF COUNCIL ON EDUCATION.

Royal School of Naval Architecture and Marine Engineering, South Kensington.

Inspector-General.—Rev. Joseph Woolley, LL.D., F.R.A.S.

Principal.—Charles W. Merrifield, F.R.S.

Vice-Principal.—Henry Martyn Taylor, B.A., Fellow of Trinity College, Cambridge.

Instructor in Engineering and Applied Mechanics.—James H. Cotterill, M.A.

Instructor in Naval Drawing.—W. B. Baskcomb. *Instructor in Engineering Drawing.*—John Maxton.

Instructor in Practical Chemistry.—John Davidson. *Instructor in French.*—Jules Penon.

The Lords of the Committee of Council on Education, after communication with the Admiralty and the Institution of Naval Architects, have opened at South Kensington a School of Naval Architecture and Marine Engineering.

The School is for the instruction, not only of Admiralty pupils from the Royal Dockyards and officers of the Royal Navy, but also of naval architects and shipbuilders in wood and iron, marine engineers, foremen of works, shipwrights, and other persons desirous of studying naval architecture.

The Admiralty have deposited their collection of naval models at the South Kensington Museum, and my Lords trust that the private shipbuilders of the country will give their assistance in rendering the collection more complete.

The course of instruction is calculated to last for three years, on the supposition that the student comes with a fair knowledge of drawing and practical geometry, and an elementary knowledge of mathematics and physics. So long as there is room in the School, however, it is not intended to exclude students whose education is less advanced.

The instruction will embrace the subjects specified for the final examinations. While there is room, students may be admitted to the special classes on professional subjects, without attending the general course.

The School is open every year from the 1st of November to the 30th of April in the following year. The students are expected to pass the summer six months in practical work, either in a dockyard, or in marine engineering establishments, public or private.

Admission.

The fee for the full course of instruction is £25 for each session of six months, or £60 for the course of three years. Students who have already paid one fee of £25 are allowed to compound for the next two sessions by a payment of £42 at the commencement of the second session.

Proportionate fees will be charged to students attending special classes only.

Persons desiring admission must apply by letter to the "Secretary, Science and Art Department, South Kensington, London, W."

Lectures.

Course of practical and experimental lectures (*see* Lecture Prospectus, published annually), which may be attended separately, are given on such of the subjects of instruction as admit of or require illustration by this means.

The public will be admitted to the full corresponding courses of Lectures on payment of a fee of £2 or to each separate lecture on payment of 1*s*. Officers in Her Majesty's Service are admitted to the full course on payment of £10 per session, and to the lectures on payment of a fee of £1.

Scholarships.

Four free Studentships will be given in competition each year if qualified candidates present themselves, and to the two best of these, Scholarships of £50 per annum. They are only open to students who have joined the School at the commencement of the session. In case all of these be not filled up in any one year, students who have studied for one or two years at the School may be recommended to compete for as many Studentships and Scholarships as may not have been filled up, if the examination passed by them at the end of the session be very satisfactory.

The subjects of the competitive examination, with the number of marks attached to each, are as follows:—

	Marks.
1. Pure Mathematics; including Arithmetic, Geometry (Plane and Descriptive), Trigonometry, and the Elements of the Differential and Integral Calculus	2,500
2. Theoretical and Practical Mechanics, or Applied Mathematics	1,500
3. Practical Shipbuilding	2,000
4. Marine Engine and Engineering	2,000
5. Physics	500
6. Chemistry	500
7. Mechanical and Professional Drawing	500

The competition will take place in the School, early in November. No person will be permitted to compete who has not already been admitted as a student, and paid the fee, which will be returned to him in the event of success.

Students whose expenses are paid by the Admiralty are not admitted to compete at these examinations, nor are they open to any but British subjects.

Collateral Advantages.

Facilities for visiting the Royal Dockyards will be granted to all the private students of the School of Naval Architecture (being British subjects) by the First Lord of the Admiralty.

Arrangements are occasionally made for the students to visit public and private works, by the courtesy of the owners and authorities of the establishments.

The Principal will afford any information in his power to parents and guardians respecting the board and lodging of those who desire to reside in the neighbourhood, and it is recommended that the students should, if possible, make arrangements to live within a radius of a mile, or little more, from the School. But the Department accepts no responsibility in the matter.

Hours.

The usual hours of study are from 9 to 12, from 2 to 5, and from 7 to 9, on Mondays, Tuesdays, Thursdays and Fridays; and on Wednesdays and Saturdays, from 9 to 12 only. The public lectures take place from 5 to 6 p.m. on two or three evenings weekly.

Inspection.

All the students are examined at the end of each session. At the end of the third session, the student will compete for his diploma of Associate or Fellow of the School.

Examination for Diplomas.

Extract from Minute of Committee of Council.

" Diplomas will be given to all persons, whether they have received their instruction at the School or " not, who pass the final examinations of the School, provided that they give satisfactory evidence of " having gone through the course of practical work recommended by the Council of the Institution of " Naval Architects. These diplomas will be of two grades, according to the success of the candidate in " the examination, the title of the higher grade being Fellow, and of the lower, Associate, of the Royal " School of Naval Architecture."

These examinations will be held annually, towards the end of April.

Subjects and Marks for the Diploma of Associate.

Group A.

Naval Architects.	No.	*Marine Engineers.*	No.
Practical shipbuilding	1,000	Practical engineering	1,000
Laying off	1,000	Steam	1,000
Usual calculations of a ship	1,000	Usual calculations of a marine engine ...	1,000
*Elementary physics	1,000	*Elementary physics	1,000
	4,000		4,000

Group B.

Naval Architects and Marine Engineers.

	No.
Arithmetic and mensuration	1,000
Algebra, including quadratic equations; and Euclid, first six books and 22 propositions of Book XI., with deductions	1,000
†Plane trigonometry and logarithmic calculation	1,000
‡Elementary mechanics and hydrostatics	1,000
	4,000

* An elementary knowledge of heat, chemistry, electricity, and magnetism, with especial reference to the errors of compasses of ships, both of wood and iron.

† Plane trigonometry as usually read, exclusive of trigonometrical analysis.

‡ Including (*inter alia*) the description and explanation of the principal mechanical and hydrostatical instruments and machines, specific gravity, and the flotation of bodies.

GROUP C.

Naval Architects.	No.	*Marine Engineers.*	No.
*Ship drawing	1,000	*Engine drawing	1,000
Total marks possible	9,000	Total marks possible	9,000

Note.—Half the possible marks to be obtained in each of the three groups as a condition of the ASSOCIATE'S diploma. This schedule will be revised from time to time as occasion may require.

SUBJECTS AND MARKS FOR THE DIPLOMA OF FELLOW.

Obligatory Subjects.

GROUP A.

Naval Architects.	No.	*Marine Engineers.*	No.
Design of a ship	500	Design of an engine	500
Principles of design of a ship	500	Principles of engine design	500
Practical shipbuilding and laying off ...	1,000	†Marine engineering and steam	1,000
†Steam and steam engine	750	Practical shipbuilding	750
‡Physics	750	‡Physics	750
§Chemistry and properties of metals ...	750	§Chemistry and properties of metals ...	750
	4,250		4,250

GROUP B.

Naval Architects and Marine Engineers.

	No.	
‖Pure mathematics	2,000	
Applied mathematics	1,000	
Applied mechanics and machinery...	1,000	
		4,000
Total marks possible for obligatory subjects		8,250
,, ,, for voluntary subjects (*see* below)		6,000
Total possible		14,250

Note.—2,100 marks to be obtained in Group A and 2,000 in Group B, as a condition of the FELLOW'S diploma. In case of failure, the examiner will judge whether the knowledge shown by the candidate is sufficient to admit of his being received as an *Associate*.

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* The ship and engine drawing will be done by the candidate at home "on honour." Instructions will be sent to any candidate applying in proper time.

† Description of marine engines, boilers, and propellers in ordinary use, and a practical knowledge of the rules for calculating nominal and effective power, evaporation, &c., and performance of steam vessels, and the use of the indicator and dynamometer.

‡ Including the elements of pneumatics, heat, electricity, and magnetism, with its application to ships, both of wood and iron.

§ A fair knowlege of inorganic chemistry and qualitative analysis.

‖ The pure mathematics will involve a fair knowledge of the calculus, of analytical geometry of three dimensions, and of descriptive geometry, and a thorough acquaintance with the principles of the mensuration of shipbuilding [or marine engineering].

Voluntary Subjects and Marks.

For Special Notice in the Diploma of Fellow.

	No.
Dynamics and hydrodynamics (higher theory of)	1,000
Strength of materials and structures	1,000
Theory of marine propulsion and of fluid resistance ... ... }	1,500
Theory of waves and of the behaviour of ships ... ... }	
Heat, in its application to the marine engine, and theory of the steam engine	1,500
*Higher pure mathematics	1,000
	6,000

No paper in this list will count for anything in the class list, or be mentioned in the Diploma, unless the Fellow obtain at least 30 per cent. of the marks in it.

Subject to this, the place of the Fellow in the class list will be settled by the total of marks obtained both in these and in the obligatory subjects. But the previous question, whether a candidate is to be received as a Fellow, will depend on his obtaining the necessary marks in each group of the obligatory subjects.

In case of failure at the examination, the student may either remain at the School for another session, at a fee of £25, or he may present himself at any future examination whenever he considers himself qualified.

Candidates who have not been students of the School will be required to produce certificates that they have been engaged for three years, at least, in—

1. Practical wood or iron shipbuilding in a dockyard;

or

2. Practical engine and boiler building in a dockyard, or in the works of a marine engineer;

or

3. Practical work as a draughtsman in a dockyard [or marine engine works], during which the candidate must have himself gone through the complete formation of the design of a ship [or of a marine engine], with the whole of the calculations included in it.

Such candidates will also be required to give references as to character and good conduct, before they are admitted to the examination.

All such candidates must apply to the Secretary, Science and Art Department, South Kensington, W. not later than the 15th March in each year.

Books and Implements.

Students are expected to provide themselves with books of study, note books, small stationery, and drawing implements. Large drawing instruments and boards, paper and ink, are provided by the department.

The Principal will be ready to advise with any student, as to the selection of books and mathematical drawing instruments.

* Including (*inter alia*) the elementary parts of calculus of finite differences, calculus of variations, and differential equations.

The following is a list of the books at present used in the School:—

	Publishers.
Todhunter, Euclid	Mc Millan.
„ Algebra	„
„ Analytical Statics	„
„ Plane Trigonometry	„
„ Spherical Trigonometry	„
„ Conic Sections	„
„ Differential Calculus	„
„ Integral Calculus	„
„ Theory of Equations	„
Tait and Steele, Dynamics of a Particle	„
Routh, Rigid Dynamics	„
Boole, Differential Equations	„
„ Finite Differences	„
Aldis, Solid Geometry	Deighton, Bell, and Co.
Woolley, Descriptive Geometry	Longman.
Besant, Elementary Hydrostatics	Deighton, Bell, and Co.
„ Hydrostatics and Hydronamics	„
Golding Bird and Brook, Natural Philosophy	Churchill.
Logarithms of Useful Knowledge Society	Walton and Maberly.
Rankine, Applied Mechanics	Charles Griffin.
„ Steam Engine	„
Main and Brown, Steam Engine	Longman.
„ Indicator and Dynamometer	„
Shipbuilding, Theoretical and Practical, by Watts, Rankine, & others	Mc Kenzie.
Buckmaster's Chemistry	Longman.
Drew, Geometrical Conic Sections	Mc Millan.
Parkinson, Elementary Mechanics	„
Goodeve, Elements of Mechanism	Longman.
Twisden, Practical Mechanics	„

The School possesses a small library of books of professional reference, which will be increased by annual purchases.

At the present time (February, 1867) there are 29 Admiralty and 15 private students.

All communications to be addressed to the Secretary, Science and Art Department of the Committee of Council on Education, South Kensington, W.

By order of the Committee of Council on Education.

Besides the fixed staff of officers, other gentlemen contribute to the instruction of the students by courses of lectures. You, yourselves, will best judge of the value of such instructions when I read you a list of the names, and of the subjects on which they have given courses of lectures.

Courses of Lectures.

Subject.	Lecturer.
1. Inaugural Lecture	C. W. Merrifield, F.R.S., Principal.
2. On the Principles of Mechanics and Hydrostatics, Machinery, and Elements of Mechanism. (Twelve lectures.)	The Rev. B. M. Cowie, B.D.
3. On the Mechanical and Chemical Properties of Iron; and on the Metallurgy of Iron. (Six lectures.)	John Percy, M.D., F.R.S.
4. On the Properties of Different Kinds of Timber; its Application and Durability. (Three lectures.)	T. Laslett, Timber Inspector, H. M. Dockyard, Woolwich.
5. On the Use and Application of Iron to form Mechanical Structures. (Six lectures.)	Professor Pole, F.R.S.
6. On the Practical Construction of Ships in Wood and Iron; and the method of combining Timber with Iron in Ship Building; and on Forms of Ships. (Eight lectures.)	E. J. Reed, Chief Constructor of the Navy.
7. On Marine Steam Engines and Boilers. (Eight lectures.)	A. Murray, M.I.C.E., Chief Engineer, H.M. Dockyard, Portsmouth.
8. On the Strength of Materials as applied to Shipbuilding. (Three lectures.)	Professor Rankine, F.R.S.
9. On the Motion of Bodies through Water, the Resistance of Fluids, and the Motion of Waves. (Three lectures.)	Professor Rankine, F.R.S.
10. On the Stability and Oscillation of Ships. (Three lectures.)	W. Froude.
11. On the Mechanism of Masts, Rigging, and Sails; and Steering Apparatus. (Six lectures.)	F. K. Barnes and N. Barnaby, Assistant-Constructors of the Navy.
12. On the Principles of Marine Propulsion. (Four lectures.)	J. B. C. Crossland, Assistant-Constructor of the Navy.
13. On Screw Propellers	F. Pettit Smith.
14. On the Calculations and the Curves used in Shipbuilding. (Four lectures.)	C. W. Merrifield, F.R.S., Principal.
15. On Magnetic Errors, Compensations and Corrections, with special reference to Iron Ships and their Compasses. (Three lectures.)	The Astronomer-Royal.

Subject.	Lecturer.
16. On the Fitting up, Equipment, Stores, Armament, and Outfit of Ships of War. (Six lectures.)	F. K. Barnes, and N. Barnaby, Assistant-Constructors of the Navy.
17. On Lloyd's Rules for Classing Wood and Iron Ships. (Two lectures.)	J. H. Ritchie, Surveyor of Lloyd's.
18. On Naval Artillery and Naval Tactics. (Six lectures.)	Capt. L. G. Heath, R.N., C.B.
19. On Board of Trade Regulations. (Two lectures.) ...	R. Murray, C.E., Engineer-Surveyor to the Board of Trade.
20. On Strength of Materials. (Two lectures.) ...	W. Fairbairn, F.R.S.
21. On some Details of the Construction of *Great Eastern*...	J. Scott Russell, F.R.S.
22. On Special Properties of Copper, Zinc, Lead, Tin, and certain other Metals employed for Shipbuilding. (Six lectures.)	John Percy, M.D., F.R.S.
23. On the Longitudinal System of framing Iron Ships as carried out in the *Annette*.	J. Scott Russell, F.R.S.
24. On the Construction of Keels, Sterns, Sternposts, and Rudders of Iron Ships.	F. K. Barnes, Assistant Constructor of the Navy.
25. On the Disposition, Construction, and Fittings of Water-tight Bulkheads in Iron Ships.	F. K. Barnes, Assistant Constructor of the Navy.
26. On the Disposition and Fastenings of the Skin Plates of Iron Ships.	N. Barnaby, Assistant Constructor of the Navy.
27. On the Beams and Decks of Iron Ships	N. Barnaby, Assistant Constructor of the Navy.
28. On the Keels, Keelsons, Floors, Sterns, and Sternposts of Wooden Ships.	H. Morgan, Comptroller's Department, Admiralty.
29. Mechanism. (Four lectures.)	The Rev. B. M. Cowie, B.D.
30. On Principles of Marine Propulsion. (Four lectures.) ...	Professor Rankine, F.R.S.
31. On the Frame Timbers, Riders, and Planking of Wooden Ships.	H. Morgan, Comptroller's Department, Admiralty.
32. On the Shelf, Beams, Waterways, Hatchways, and Decks of Wooden Ships.	H. Morgan, Comptroller's Department, Admiralty.
33. On the Methods in use of Preparing, Fitting and Fastening Armour Plates.	H. Baskcomb.
34. Machinery. (Eight lectures.)	J. Anderson.

Subject.	Lecturer.
35. On Marine Engineering and Theory of Waves and Oscillation. (Ten lectures.)	J. Scott Russell, F.R.S.
36. On Principles of Calculation, as applied to Naval Architecture. (Three lectures.)	C. W. Merrifield, F.R.S.
37. On Practical Shipbuilding, including Iron Shipbuilding, Wood Shipbuilding, the building of Composite Ships of Wood and Iron, the sheathing of Iron Ships with Wood and Iron, and the local strengthening of Wooden Ships by means of Iron. (Fourteen lectures.)	E. J. Reed, Chief Constructor of the Navy.
38. On Iron and Steel; their characteristics and mode of working. (Six lectures.)	John Percy, M.D., F.R.S.
39. On the Principles of Machinery as applied in practice. (Six lectures.)	John Anderson, Royal Arsenal, Woolwich.
40. On the Stowage and Equipment of Ships. (Six lectures.)	N. Barnaby, Assistant Constructor of the Navy.
41. On the Construction and Theory of the Marine Steam Engine, the Marine Boiler, and Marine Propellers. (Fourteen lectures.)	J. Scott Russell, F.R.S.
42. On the Principles of Structural Ornament; (1) of the expression of Structure in form alone; (2) in design and decoration; and of Structures modified to suit principles essentially decorative. (Two lectures.)	C. W. Merrifield, F.R.S., Principal.
43. On Marine Locomotion. (Four lectures.)	Professor W. J. Macquorn Rankine, F.R.S.

In addition to these courses of lectures on detached subjects, systematic courses of study are provided by the professors on the subjects contained in the syllabus for the final examinations.

Examinations.

The best proof of the success attending these courses of study and instruction, will be found in the knowledge attained by those students, who have now passed through the whole course of three years' study; and so far as I have been able to form a judgment on this subject, I venture to say, that at the age of from 21 to 25, these young men start with an amount of knowledge which very few of the past generation had attained, after many years of laborious practical experience and painful blundering in the dark.

Practical Work done in the Dockyards.

I believe it is to the present Comptroller, and to the Chief Constructor of the Navy, that we are mainly indebted for having organised, on behalf of the students, a systematic course of work in the dockyards. I have seen the records of work and of observation kept by those students: they are carefully examined and superintended by the competent authorities in the dockyards and at the Admiralty; and I have asked permission to lay some of them before you, that you may judge for yourselves how far the habit of systematically noting down the results of their observations is likely to advance their future usefulness.

Conclusion.

As many of these students are in the habit of attending the meetings of this Institution, I would venture to give to them some of that advice which an old member of that profession on which they are about to enter may have the privilege of giving to those who are to follow him. It has been asserted by enemies of technical education that it is not an advantage but an evil. Make it the duty of your life to refute that accusation; shew that, as practical men, you are not the worse, but the better, for the systematic scientific knowledge you have received. Men will say of you that you are puffed up with the little knowledge that you have acquired; and that you believe, because you know many things other people do not know, that you therefore know everything better than those who have passed their whole lives in a dockyard. If you follow my advice, you will go into a dockyard, or shipbuilding establishment, as if you had everything to learn. Let me assure you, that a skilled mechanic, who has spent his life in a dockyard, knows a hundred things of which you have yet no idea; take great pains to learn of him everything he knows—become his humble pupil—let him teach you how he handles his tools, the way he has of going to work, the easy ways he has found out of doing hard things, how with heavy work he can make it light by sleight of hand; and if I were you, I should take care that within a year after I had fairly set to work in a dockyard there should be no bit of real good clever handicraft, that I could not do as well as any man in the dockyard. Do all this, and you will never regret the three winters you have spent in study, and this Institution will never regret the pains it took to initiate the School of Naval Architecture.

DISCUSSION.

Mr. GALLOWAY: May I be allowed to say that I am very much impressed with the importance of this valuable Institution of Naval Architects, and I am quite sure that the subject matter of that Paper which has just been read, must add a zest and give a stimulus to every gentleman connected with the Institution, and especially would I say that it is of the highest importance to the young gentlemen who are learning the business or the profession of naval architects. I would say further, that both the professional and the national aspects of the subjects which have been brought under their consideration, are well worthy of the closest investigation, and the most deliberate reflection. You have, young gentlemen, before you the inventive genius of the past as well as of the present age, and, through the medium of the printing press, you are also indebted to inventors, for the means of obtaining all that knowledge and information which is best calculated to fit you for the discharge of life's important duties. And now, let me for two or three minutes, if you please, continue—

Mr. MERRIFIELD: I am afraid I must rise to order. The subject now before us is the discussion of Mr. Scott Russell's Paper. I am sure, Gentlemen, you generally shew yourselves exceedingly willing to listen to Mr. Galloway, but I am afraid we hardly have time to listen to an address to the students of my School.

Mr. GALLOWAY: I do not want to give offence. If I had not understood that there was to be some discussion on the Paper I might not have risen as I did.

Mr. E. J. REED: Mr. Chairman and Gentlemen, I hope that Mr. Galloway will not think that this Institution is in any way unkind or ungenerous as regards the attention which it gives to him, seeing that he has no status in the Institution, but is merely a visitor, and that he very frequently indeed avails himself of the courtesy shown to all visitors to the Institution desiring to take part in the discussions.

Mr. GALLOWAY: I was just going to say that I thank the President, the Secretary, the Council, and the Institution generally, for the privileges I have enjoyed of being present at and taking part in these meetings. It was by mere accident three years ago that I became aware of the existence of the Institution. Mr. Scott Russell met me at the door, and that led to my acquaintance with the Institution. I thank you heartily for the liberties I have enjoyed, and if I have ever said anything personal accept my apology. I have spoken as a man, honestly, from my convictions and experience, and upon national grounds. I claim that right. I trust you will forgive me if I have done anything wrong. It was not in my heart to do so, and I now again thank you for your kindness.

Mr. MERRIFIELD here read a letter which had been received from the President, announcing his regret at his inability to be present at the closing meeting.

Mr. REED: I think a peculiar value must be attached by every one who is interested in the progress of naval architecture in this country, and in the world, to the Paper which Mr. Scott Russell has so ably composed and laid before this meeting. I have been, as you are aware, fully cognisant of every step taken in the establishment of the School of Naval Architecture; and I wish to supplement, in one or two words, his very able Paper, on a point on which I am sure he was brief, only because of our time having nearly elapsed, and that is with reference to the instruction of the students in the dockyards. I know

Mr. Scott Russell would desire that I should add a word or two upon that subject. The present students of the School of Naval Architecture have the peculiar advantage, if I may be allowed to say so, of being under the control in the dockyards of a number of persons, including myself, who suffered somewhat in their own School of Naval Architecture from a want of due attention to practical study in the dockyards. It is well known that we were not so efficiently helped in that respect as we could have wished, and that a little difficulty arose at the time of our departure from the School, in consequence of circumstances of that nature. I, therefore, for one—and I am sure my assistants also share my feeling completely in that respect—have been very anxious that so far as in us lay that error, or oversight, should not be repeated with reference to the new School; and it has been our anxious care to arrange for the students means by which they should possess themselves, as fully as was possible, of the practical knowledge to be acquired in the Royal Dockyards. In saying that, I am bound also to add that, not only has that course been sanctioned by the Controller of the Navy and the Admiralty, but it has been carried out by their express desire. This applies, not only to the late Board of Admiralty, but also to the present Board, both Boards having shown, without a single exception, the greatest possible desire that this School should be made as efficient and as useful as possible. I doubt whether we are not past the period when hostility to scientific schools of that nature is likely to produce any result such as was met with in times gone by,—for more than once the Schools of Naval Architecture were closed by politicians who took views contrary to those which have been so well expressed by Mr. Russell upon the subject. What happens to the students in the dockyards is principally this:—They are put under the care of the master shipwright; they are instructed to be continually at the actual work, to record on paper where they have been, what they have been seeing, and, in so far as is practicable, to make sketches of the works they see in progress—not only sketches, but detailed sketches. Not finished sketches, there is no attempt of that sort. In fact, I have very much discouraged the making of finished sketches, because I know that by that means there is a great expenditure of time in doing one thing over two or three times. What we want them to do is, thoroughly to examine the work carried on, to make themselves cognizant of it down to the minutest details, and to impress it upon their minds; and that is a very important point, because people who are engaged in professional studies know very well that there is a great deal of knowledge that passes through the mind, while but little knowledge, comparatively, abides in the mind unless special means are taken. I was much pleased to find that soon after the system of keeping diaries by the students came into operation, the students themselves expressed an anxious desire to be allowed to take those records back for their own permanent use after they had completed their term at School. I believe that that course has been partially, though not wholly sanctioned, but I anticipate no difficulty in giving it effect when the period of study is over. I should be very sorry, Sir, to lose this opportunity of saying that I think all of us who have taken an active part in this School, or rather, an anxious interest in this School, are very much gratified indeed with the mathematical teaching which they have received, and I must say that I think the efficiency of that teaching is very largely due indeed to the eminent fitness of Mr. Merrifield for imparting it, and to his great zeal in carrying out the duties of his position. I think, too, that the practical instruction which they have received in the yards, and which we have endeavoured to facilitate as much as possible, has been as satisfactory as their scholastic instruction. The time has now nearly arrived when a number of these students will leave the School, and when they will have to be put to actual duties; and Mr. Scott Russell has so well intimated to them the spirit in which they should proceed from the School to the actual work, that it is almost unnecessary to say a word more. But yet, two things may be

said with some advantage; and the first is, that while every disposition exists to give to these students a favourable position, no disposition exists to put a premium upon the fact of their having been to that School, apart from the special ability and fitness which they may shew for rendering good service to the public and to the country. It is very difficult indeed to send these students properly out; because, if you send them into the lower positions in the dockyards, you are apt to excite feelings which are not always satisfactory, in the least judicious of the students themselves, and among the men with whom they mix. There are great jealousies, and always will be, against educated men, on the part of those who are uneducated; because, it is a prominent feature of education, that those who possess it alone understand its value; but, at the same time, there is a great risk of young gentlemen, who have received special education of this sort, failing to appreciate the value of that other education, which they have not so long received as the men among whom they must now move; and also, of their failing to appreciate the services of good, practical, and experienced officers. I have great hope, from the spirit which pervades that School, as far as I have been able to test it, that we shall have as few difficulties of that sort, as can possibly be expected under the circumstances. I take this opportunity of saying, in the presence of many of the students, that I sincerely hope they will co-operate with those gentlemen, who have been so anxious to establish and promote the interests of this School, and will conform to the anxious desire of the Admiralty, by recognizing fully, and at first, the extreme importance of seeking to make themselves as valuable as possible, from the very moment when they enter into actual work. I wish, also, in the second place, not with a view to discouraging, or unduly discouraging any of them; but with the view of putting them in a position thoroughly to appreciate their future—to put them on their guard against supposing that the number of students who enter that School can all come out, and all rise together, and all share equally in future rewards. It is a peculiar feature of the public service in the dockyards at the present time that the promotions are ruled essentially by competitive examination. But at the same time it is advantageous that these young gentlemen should feel, when they have taken their first position in the dockyard, that it is solely by their own established and demonstrated merits that they can hope to rise. I shall never feel disposed myself to give undue advantages to any young gentleman after his first start upon the consideration that he has been to this School, unless he shews that by the fact of his having been there he has established a fitness to do specially good service in the public interest. I will only say, Sir, in conclusion, while the meeting is so quiet and attentive, that there will be on the 1st of May, I believe, at South Kensington—I do not know whether it will be public—(Mr. MERRIFIELD: Yes)—a meeting to which the Members of this Institution will be invited, and at which the drawings of the students will be exhibited. It is hoped that some of the members of the Admiralty will be able to be present, and I shall have the pleasure of reading a Paper shewing what their studies have been. I mention it now in order that the Members of this Institution, at any rate, may on that occasion evince the interest which they have always taken in the formation and promotion of this School.

Mr. MERRIFIELD: I may say that I should have been instructed to give you an invitation now on behalf of the Science and Art Department, but there is some little question as to the possibility of the afternoon now fixed clashing with the intended laying of the first stone of the new building by Her Majesty, and consequently we must keep out of the way of that. Otherwise you would have been invited at once. Perhaps I may be permitted to thank Mr. Reed and Mr. Scott Russell for the extremely kind terms in which they have spoken of me, and to assure you all, Gentlemen, that I shall certainly do

my best to deserve those encomiums which I can hardly accept hitherto as being due. There is only one point on which I should like to speak of the School under my charge, Gentlemen, and that is, that as it is possible that some of you may be either now, or at some future time, sending one or two of your children to this School, I thought you might like to hear a word or two as to the kind of education which is desirable to prepare them for us. Now, if I were in any other country where exact technical education is much more widely pursued than it is in this country, I should say, give them a good, general, scientific education, and send them to us just as they are. But, unfortunately, that is not the style of education that is usual in England at the higher schools, such as Eton, Harrow, Westminster, and Winchester. I am not going to criticise the public school system, but simply to remark that the object of those schools is to fit young men to fulfil the duties of country gentlemen, squires of parishes, and so on. I find no fault with the schools which educate that class of men, nor with those schools which are for the sons of large merchants who want to educate their boys for the counting-house. But many schools of the middle class try to imitate the large public schools in giving to their students an education that is adapted solely and entirely to a very different class. The consequence is, that many of the boys of the middle class are quite as deficient in the studies they want, as the boys of the higher class are in the studies which they do not want. I should like myself to see the public school course made a little more exact, especially in the matter of mathematics; and I should like to see the classics taught, more as languages, than as examples of grammar. I am quite aware of the argument used in favour of the present system, that its object is not to give information, but to train the mind for its reception. My answer to that argument is, that that mode of training a man would be very well, if he were going to live to the age of Methuselah. However, the middle classes do require to have a far more exact technical education than they now have. But the main points in which they are deficient—and I have had some practical experience in this matter—are, first, a knowledge of elementary mathematics, and next a knowledge of practical drawing. I do not want to make artists of them. I do not care about their being able to draw a face that is anything else than a caricature, but I do want them to be able to make a sketch of anything which they may be ordered to construct, and I also want them to have a moderate knowledge of elementary mathematics. With regard to arithmetic, I never knew a man of eminence having to do miscellaneous work in after life, who had neglected arithmetic as a boy, but he had to give to it four times the labour at a later period. As to the amount of mathematics, I do not want much. I want a good knowledge of practical geometry. I should like to get Euclid, and algebra; and if you will give your boy this, and make him a moderate draughtsman, he will not fail in the School of Naval Architecture for want of preliminary education.

Mr. Scott Russell: I have only, in reply, Gentlemen, to thank you for listening so attentively to my long Paper.

GRELL'S PATENT KEEL RUDDERS.*

By W. J. Henderson, Esq.

[Read at the Eighth Session of the Institution of Naval Architects, April 13th, 1867, J. H. Ritchie, Esq., Member of Council, in the Chair.]

In accordance with instructions received from Mr. J. H. Grell, of Hamburg, I have the honour to lay before you a discovery made by him of a system of manœuvring and steering sailing or steam vessels with very great rapidity and effect.

It will readily be admitted that the means of control hitherto provided for the navigation of ships of all kinds has not corresponded with the great increase of motive power which the demands of modern civilization and the advance of engineering skill have combined to produce. Great progress has been made in the best forms of construction. The natural laws which lie at the basis of the science of Naval Architecture are being mastered: the old form of the hull, so well known in the Roman galley and other ancient vessels, has long been discarded, and the "clipper" and ocean mail steamer are forms reproduced even in the child's school book. Yet, with all the progress of the last half century which has reduced the distance to America to a ten days journey, and enabled the merchant to obtain from China a cargo in 90 days, we have been left almost up to the present time with no better means to direct this vast accession of power than the ancient and primitive form of rudder, which, though it might have suited the habits of our ancestors, is quite unequal to the exigencies of modern times.

In order to shew the necessity which exists for an improvement in the form and position of the rudder in a ship, permit me to draw your attention to a few facts regarding that which is in common use; and here allow me to observe that for all practical purposes the proportion of efficiency must be sought in the capability of resistance at the moment of greatest trial. Every shipbuilder knows that for immense and extreme strain he must provide; and the history of every voyage fully

* Received 26th March, 1867.

justifies precaution. Whether it be the hull, engines or rudder, the trial will be, not when in port but when in mid-ocean, in storm and hurricane and far from all aid, or nearer shore, when the cry of "Breakers ahead!" or danger of collision, for the moment places the safety of ship, cargo, and passengers in the amount of control which the rudder exercises over the vessel's course. In such circumstances the word passed to the man at the wheel has frequently come too late, the means at his command being insufficient to prevent calamity.

I would here state what I consider to be the principle deficiencies of the common rudder, which the plan of Mr. Grell is intended to remedy:

1st.—It is often carried away by the force of the broken water, which, agitated by winds, whilst it affords no firm fulcrum against which the rudder can act, is the very means of its destruction. This danger would be removed, were the rudder entirely submerged, or all that part of it cut away which rises above the depth to which the storm wave penetrates below the ordinary sea level.

2nd.—It is not sufficiently powerful in altering the vessel's course upon a sudden emergency. Fully one-fourth of all the vessels lost on the Coast of the United Kingdom and in the surrounding seas, are the result of collisions. But there are usually a few moments in the haziest night between the sighting of a vessel and the actual period of contact, and with his vessel under more complete control, a captain under such circumstances would much more frequently escape. In almost all recent cases of collision the helmsman has done his best, but too late, to avoid the dreadful crash; valuable lives have been sacrificed, much property lost, and expensive litigation incurred, very much of which might have been avoided had the means of control and rapid manœuvring been increased in proportion to the motive power.

3rd.—The existing rudder, while it has no directing power when the vessel becomes unmanageable, acts as a drag upon the vessel's progress and complicates and increases the influences against her.

To overcome these evils by providing an efficient remedy, the following plan of Mr. Grell is designed, and it promises to achieve the desired object, and to increase the facility with which vessels may be handled, to a very wonderful extent.

In addition to the ordinary rudder, one, two or more longitudinal openings are made in the "dead wood" above the keel, and which may extend from the sternpost to one-third of the ship's length, and from the stem in a corresponding manner aft,

according to the size of the ship and the necessities of the case, though for ordinary requirements one opening near the stem is sufficient. Into one or all of the openings made, rudders are swung by vertical shafts passing through their centre to the deck, and connected with the requisite gearing to the steering wheel. When the rudders are not turned, they form a part merely of the ship's keelson or the dead wood in which the openings for them are made; when turned as the ordinary rudder, they exert a most remarkable influence on the vessel's course, as will hereafter be described.

The advantages of this plan for steering are numerous; it will be sufficient to specify some of the more prominent.

1st.—The rudders are entirely submerged. In the greatest storm they are perfectly reliable. They are removed from all contact with the surface of the water, and instead of being exposed to the destructive action of the waves, or, in the case of a ship of war, to the enemy's shot, they are by their position protected by the vessel itself, and in all cases retain their full efficiency.

2nd.—The difficulty of keeping a vessel up to the wind in a heavy sea is well known, and it often goes almost beyond the power of human endurance to steer a ship. But by the action of the additional rudders, fewer men are needed and an immense increase of steering power is obtained, and from their axis of motion being in their centre, the rudders when turned project equally on both sides of the keel-line or longitudinal diameter of the vessel, and from that cause alone have more than double the power of the existing rudder in turning and manœuvring; while, if placed right athwartships, they may be used as a retarding and deadening power against the momentum in case of collision, as well as to facilitate the vessel's progress in a current such as the Gulf Stream, &c.

3rd.—By the openings made when the rudders are turned, the resistance of the stern, and of the long unbroken line of the vessel in turning is so much reduced, that the vessel answers her helm in the most rapid way yet known, and can be turned completely round in her own length.

4th.—In reversing screw-propellers, while the ordinary rudder is powerless for purposes of direction, these rudders have been found to possess an entirely satisfactory directing power.

For ships of war in action, owing to the entire change in naval tactics, it is evident that this invention will be most invaluable. By the rapidity with which a vessel can be handled when supplied with these rudders, it would be impossible for

her broadside to be caught by a "ram," and thus the danger to wooden vessels, so imminent by the introduction of these powerful engines of destruction, would be greatly reduced; a wooden ship, by the speed with which it could alternately deliver its port and starboard broadsides, would become a match for any antagonist, and by its rapidity in turning would acquire most of the advantages of a "turret ship."

To smaller vessels, such as tug-boats, river-steamers, &c., the invention in a modified form, by the introduction of the longitudinal openings merely, and using the ordinary rudder, may be applied most successfully. Mr. Grell has built a river steamer on this plan, 60 feet in length, with a 14 feet 6 inch breadth of beam, which is now in constant operation on the River Elbe, and which, with a speed of 9 knots per hour, makes a complete circle in 58 seconds, fully justifying the favourable opinion expressed regarding it by all nautical men who have seen it.

Thus, the invention of Mr. Grell claims for itself the highest attention of all naval intelligence. Its introduction will doubtless cause a complete revolution in steering power, and be the means of shortening to a great extent every voyage. In the navigation of intricate channels, or threading the mazy pathway of a field of ice, the mariner will find himself by means of it in possession of a power which will make his vessel secure, his cargo safe, and his passengers at ease, as far as human foresight and prudence, allied to strong means of control, can be of use.

I have, perhaps, presumed too far in trespassing on your attention, and in giving way to my own thoughts; but I was unwilling to leave anything unsaid which might induce you to consider with due attention the discovery which the inventor was anxious to lay before you. I feel convinced that in the hour of trial the vessel which is provided with such a steering power, will be found as superior to the vessel with any other form of rudder, as strength is superior to weakness, or the steamer on a lee shore is superior to a sailing vessel.

DISCUSSION.

Mr. Reed: May I ask Mr. Henderson if I understood him rightly in intimating that these rudders would act as propellers in the Gulf Stream?

Mr. Henderson: Certainly not as propellers, but simply as exposing a broad surface to the action of the current. It is not a necessary thing; it is at the discretion of the captain.

Mr. Reed: I merely wanted to know whether I was to understand that you made that suggestion.

Captain Henderson: May I be allowed to make some observations, seeing it is now some six and twenty years since I built the river-steamer *Assam?* That steamer is now in existence; she is 450 tons, and 100 horse-power. The rudders were balance-rudders, in the bow and in the stern. After twenty years' residence in India and China, and observing what was done in the Chinese boats, in 1837 I designed this *Assam* steamer, which is now working in India. I have had much pleasure in hearing my system of balanced rudders mentioned to-day; but it is rather curious that the *Bellerophon's* rudder should be so much like mine, with this one exception, that mine has been practically proved, to a very large extent, through six and twenty years; and I have found that this very year its principle has been adopted by Mr. Reed, that is a stern balance-rudder. I believe a modification has taken place. For many years I did not patent it; but in 1858, when I was about to put it into a large number of vessels, I found that one of the builders intended to patent what was mine, so I patented it, and from that day to this I have steadily persevered. I have built three vessels of my own, which are now in the Thames. One of them has been there for eight years making experiments, and I think I have now a perfect vessel, which is still to be seen in the River Thames, and which I invite any gentleman to visit. In the *Bellerophon*, Mr. Reed has simply adopted what I proposed six and twenty years ago. I think Mr. Henderson said his vessel was 68 feet long.

Mr. Henderson: Sixty.

Captain Henderson: I can only say that mine turns the circle in sixty-five seconds. The gentleman may not have seen or heard of my *Assam* before, but she is six and twenty years old. Though he is a namesake of mine, I have not had the pleasure of seeing him before, but I should like to co-operate with him in bringing about what I believe to be a great and valuable improvement. I can safely say I have studied it for many years.

The Chairman: You have had some experience, Mr. Scott Russell, in fitting rudders into dead wood.

Mr. Scott Russell: Oh yes, you can do it.

The Chairman: Balance rudders too, have you not?

Mr. Scott Russell: Certainly; but the ordinary rudder is, for general purposes, more accessible and convenient. The rudder in front of the screw, down at that part of the keel, was not my invention, but was originally invented by Mr. Henwood, of Her Majesty's Navy. He invented a rudder in front of the screw, where one of these is placed. This invention is peculiar, not in that respect, but in having a number of rudders instead of one in that place, and therefore there is not the least competition between

what Mr. Henwood and I may have done and this invention, because they are, in that respect, totally and entirely different from one another. I may say there is a little difference in the action of the rudder before the screw and the action of the rudder behind the screw. The action of the rudder when it is before the screw has this great want, as I found, that when the screw turns it does not throw water upon the rudder. Now, when the rudder is abaft the screw it has the advantage, that, when the screw turns, it throws water upon the rudder, and therefore, as you are well aware, Sir, a screw vessel standing still can, by suddenly turning her screw full power, turn round almost upon her heel. The disadvantage of putting the rudders as they are here obviously is, that when the vessel goes on the ground, or touches the ground, these rudders are very apt to be injured, and there is a great deal of difficulty in getting at them to repair them.

Sir E. BELCHER: The question of rudders, as viewed by seamen, is the possibility of removing the rudder if it is injured, and of shipping another rudder, even at sea, if you lose your rudder. But by this system I do not see how it is possible, if any accident happens, to remove the rudder, or prevent its becoming an absolute evil.

A MEMBER: I do not think that there is any novelty to be claimed by this gentleman, for within five minutes' walk of this room many gentlemen must have seen many times, during the last twenty years, a halfpenny steamer running between London Bridge and Hungerford Piers, which has a rudder at each end like this, and a crutch to secure the foremost one, and to liberate it when it is required to be brought into use. It is now twenty or five-and-twenty years since I first saw two steamers fitted with rudders like this in the dead wood, and those vessels are running now.

Captain HENDERSON: May I be allowed to say that there is a vessel, H.M. gunboat *Water Witch*, which is fitted with extraordinary hydraulic machinery, and which also has two large bow and stern rudders. The relative disadvantages might easily be tested in that ship by fitting balanced rudders in part of the space now occupied by what may be termed barn-door rudders.

ON DIFFERENTIAL FRICTION BRAKES.*

By Robert D. Napier, Esq.

[Read at the Eighth Session of the Institution of Naval Architects, April 13th, 1867; J. H. Ritchie, Esq., Mem. Council, in the Chair.]

The principal object of this Paper is to shew how friction brakes can be made automatic in their action for preventing the revolution of windlasses and other machinery in one direction, while leaving them free to turn the other way, and to explain several models illustrating the application of this self-holding arrangement for various purposes.

By a differential brake, I mean a brake consisting of a band surrounding, or partly surrounding a wheel, and so connected to a lever, that turning the lever on its fulcrum tightens one end of the band, while at the same time it slacks the other at a different rate, in consequence of which the absolute amount of tightening or slacking is the result of the difference between the two motions.

There are two distinct and nearly opposite objects that can be attained by the differential action referred to, according to the manner of applying it; the one, as in Appold's brake, is to regulate the amount of strain required to turn a wheel, so that, while it can never fall very far short of a given weight, it can never exceed it; the other object, as in the various applications to which I wish for a short time to direct your attention, is to make a very small weight on the brake lever act so as to make the wheel immovable as long as desired in one direction, whilst leaving it free to turn in the opposite direction; and as this can be accomplished conjointly with reserving the power of vecring out with perfect ease and safety, either slowly or quickly, the advantages of applying such brakes in place of the usual ratchet and pawls to ships' windlasses must be apparent. Common friction brakes, consisting of a band partly surrounding a wheel, and connected to a lever, are arranged in three somewhat different ways, of which, as a matter of course, one only is correct.

* Received April 16th, 1867.

Frequently both ends of the band are jointed to the lever in such a way that the turning of the lever on its fulcrum tightens both ends of the band at once; this, though perhaps the commonest, is decidedly the very worst arrangement. In the other two ways, one end of the band is attached to a fixed bolt or pin, and the other end to the lever; but in the one case the lever acts on the end of the band that pulls the wheel in the direction opposite to that in which the hoisted weight or other strain tends to turn it; and in the third way the lever acts on the end of the band that pulls the wheel in the same direction as that in which the hoisted weight or strain acts.

This last arrangement is decidedly the best, in so far as it requires much less weight on the handle to keep the wheel from revolving than is necessary by the second mode; for this reason, that the strain is always much less on the end of the band, which pulls the wheel round the same way as it is revolving or tending to revolve, than on the other end. The difference, when the wheel is wholly prevented from revolving, is equal to the tangential force produced at the circumference of the wheel by the hoisted weight, and when the wheel is revolving, the difference is equal to the total friction then existing between the wheel and the band, and it is by taking advantage of this circumstance, that I have been enabled to make friction brakes perfectly self-holding in one direction, whilst they leave the wheel free to turn the other way.

If a wheel be partly surrounded by a flexible band, of which one end is attached to a fixed bolt, and a strain be put on the other end, then, if the wheel be made to revolve, and the co-efficient of friction be constant, the ratio of the strain on the one end of the band to that on the other, will be constant. If we make K represent this ratio, then, if the smaller strain of the two be represented by S, the greater strain will be K S, and it can be proved that $2{\cdot}7288\ c\ t = \log.\ \mathrm{K}$ where c is the co-efficient of friction, and t is the number of turns, or fraction of a turn, that the wheel is in contact with the band, and as already stated, the smaller strain S, will be that which pulls the wheel in the same direction as it is revolving, and the greater strain, K S, will be that which pulls against the revolution of the wheel; and it is evident that in so far as this is concerned, it is immaterial which end of the band is attached to the fixed pin, and which to the lever, by which the strain on the band is regulated.

Fig. 5, Plate VII., represents a common brake, in which one end of a flexible band is attached to the fixed pin D, and the other is jointed to the handle H at A, on which a weight w is suspended.

Now, if we make the arm $\mathrm{F\ B} = \frac{\mathrm{F\ A}}{k}$, and make the weight w just heavy enough to produce sufficient friction between the band and the wheel, to prevent the latter from turning round, by the action of a weight suspended from E, it is obvious that

a strain K w, or its equal K S at B, may be substituted for the weight w at A, without affecting the equilibrium between the friction and the moment of the wheel, caused by the weight suspended from E; but the strain on D d is equal to K S, therefore, if we connect the end D of the band by a link to B, and take away the pin D, we shall get the desired strain to support the hoisted weight, without any weight on the handle:—in other words the brake will become self-holding; and as this would be the case, however large the hoisted weight might be, it follows, that if the brake is just self-holding for one weight, it will be in the same condition for any other; and also, that a slight pressure on the handle in one direction will free the brake, and allow the weight to descend; and a slight pressure the other way will prevent the descent, for it will be observed, that by moving the handle H towards I, we move A faster in one way than B travels the other way, and consequently that movement will tighten the band round the wheel; whereas, on the same principle, the reverse movement will slack the band. It will also be observed that the friction caused by turning the wheel to the right acts on the lever to make it tighten the band, and in the reverse way it acts so as to slack it, from which it follows, that by keeping a small strain on H I, we shall get a similar action to that of pawls; while, at the same time, we retain the power of easily slacking back the hoisted weight.

A very convenient and simple rule, applicable to all practical cases for ascertaining the ratio K, so as to know how to proportion the arms F A and F B, is the following equation, $K = \frac{f + 3\,t}{f - 3\,t}$, where f is the reciprocal of the co-efficient of friction, and t is the fraction of a turn in contact. Whenever the co-efficient of friction is less than $\frac{1}{6}$ this is practically correct; for example let the co-efficient of friction be $\frac{1}{9}$ and the band be in contact a whole turn, then $f = 9$ and $K = \frac{9 + 3}{9 - 3} = 2$, that is, the strain on the one end would be double that on the other. This rule is not empirical, but depends for its accuracy on the same principle that the square, cube, &c., of $1\frac{1}{n}$, when $\frac{1}{n}$ is small, are nearly equal to $1\frac{2}{n}$ or $1\frac{3}{n}$, &c.

Fig. 6 represents a differential brake somewhat differently arranged.

If the fulcrum F were kept in a fixed position, we should get a similar action to that in Fig 5, allowing the wheel to revolve to the left, and preventing its movement in the opposite direction—on the supposition of the distances F A and F B being properly proportioned. Your time will not allow me to enter upon the question of the amount of saving of power in the working of a brake where these proportions are not sufficient to make the brake wholly self-acting, at present I speak only of cases where the differentialism is sufficient to prevent slip altogether in one direction.

Now if by means of the link D F we move the fulcrum F upwards, we must turn the wheel to the left, and if we suppose another self-holding brake to prevent it from turning to the right, we can, after raising F a certain distance, lower it again, of which the effect will be, first to let the other brake take the strain, then to slack the band, and then by means of a small chain *e e* to draw the band round for another grip, and so by alternately raising and lowering the fulcrum F we can turn the wheel in one direction, and by this means we can get a hoisting purchase without spur-gearing.

I may mention that besides using this for hoisting weights it has been employed with very great advantage for the purpose of screwing down screw piles for bridges. Piles have by this means been screwed down five and twenty feet without requiring, after being once started, any other attendance than that of a man at a steam winch.

Referring again to Fig. 6; if the fulcrum be lowered till the lever F A touches the point G, a further movement will slack the band and leave the wheel free to revolve either way. This is the plan adopted in the model windlass on the table for throwing the hoisting purchase out of gear.

Subjoined are four formulæ for ascertaining the weight required on the lever at A to support a given strain at the circumference of the brake wheel, where the brake is not self-holding, and the strain that would be supported by a given weight on the lever.

$$h = \mathrm{W}\left(\frac{1 - k\frac{l}{\mathrm{L}}}{k - 1}\right) \qquad h' = \mathrm{W}\,\frac{k - \frac{l}{\mathrm{L}}}{k - 1}$$

$$\mathrm{H} = w\,\left(\frac{k - 1}{1 - k\frac{l}{\mathrm{L}}}\right) \qquad \mathrm{H}' = w\,\frac{k - 1}{k - \frac{l}{\mathrm{L}}}$$

Where L is the long lever, F A; and l, the short lever F B; W is the force exerted at the circumference of the wheel by the hoisted weight; w is the force exerted at A by the weight on the handle; k, as already stated, is the ratio of the strain on the one end of the band to that on the other. The letters in this and following paragraph refer to Fig. 5.

h is the force required at A to support W suspended so as to call the gripping action into play, and h' the weight required at A when the weight W tends to slack the band as in Appold's brake.

H is the holding power of the force w; that is the strain that w would support at the circumferences of the wheel in the direction that calls the gripping action into play, and H′ the corresponding holding power in the reverse way; that is, acting as Appold's brake.

Example:—Let the friction band be a flexible strap in contact with the wheel $\frac{2}{3}$ of a revolution; F A = L = 6 ins.; F B = l = 3 ins.; the co-efficient of friction = C = $\frac{1}{10}$,

then $f = 10$. Required, the tangential force at the circumference of the brake wheel necessary to turn it, first in the direction that tends to tighten the band, and second in the direction that tends to slacken it, while a weight of 1 cwt. is suspended at A: $t = \frac{2}{3}$ and $f = 10$, therefore

$$K = \frac{10 + (3 \times \frac{2}{3})}{10 - (3 \times \frac{2}{3})} = \frac{12}{8} = 1\frac{1}{2}$$

also

$$W = 1 \text{ cwt.}, \quad H = w \frac{k - 1}{1 - k^{\frac{t}{L}}} = 1 \text{ cwt.} \times \frac{1\frac{1}{2} - 1}{1 - (1\frac{1}{2} \times \frac{3}{6})} = 2 \text{ cwt.}$$

being the first strain required, and

$$H' = w \frac{k - 1}{k - \frac{t}{L}} = \frac{1\frac{1}{2} - 1}{1\frac{1}{2} - \frac{1}{2}} = \frac{1}{2} \text{ cwt.}$$

being the strain the reverse way.

Description of Models.

In designing the model of a windlass, the first consideration was given to the question of veering out; and in fact, that is where the principal advantage is gained by using self-holding brakes in place of pawls, for in that is mainly involved the safety of the men and the ship.

There are two hoisting purchases and one pawl-brake. The hoisting purchases are supposed to be generally worked alternately; but when any temporary extra strain comes on, such as breaking the anchor out of the ground, all the men can immediately place themselves in the position in which they can employ their strength to greatest advantage; and the instant the extra strain is overcome, they can commence working alternately; and the double purchase can be put on, by shifting the pin in the hoisting lever, without even taking the strain off the handles.

For veering out, it is not necessary to throw the hoisting purchases out of gear, for that also is self-acting. By simply lifting the pawl-brake handle, the barrel is allowed to go backwards, taking for a certain distance the hoisting handles with it; but, on arriving at a given position, the hoisting brakes free themselves, and if the pawl brake be left quite slack, veering out can be regulated as well, if not better, by the hoisting handles, or by either of them, as by the central or pawl brake. When riding at anchor, all three can be made to act as pawls, so as to divide the strain in heavy weather.

With the assistance of a wedge or a screw, as in the model, when more chain is wanted to be payed out while riding, the brake can be so adjusted that a foot or two will veer out at a time, and that only when a more than usual strain comes on, so that, in place of running the risk of carrying away everything, as is frequently the case in paying out more chain, the effect is to relieve the chain.

The efficiency of these windlasses does not depend so much on nice workmanship as in giving all the joints plenty of freedom, and as all the surfaces are lubricated when desired, there is no risk of slipping being occasioned by grease getting on the rubbing surfaces. In this respect the gripping action is essentially different from that of any other frictional windlasses, and wearing of the surfaces very little, if at all, affects the holding power.

The frictional chain stopper and veering-out gear, represented by the smaller model, is intended for ships using capstans. The ship is supposed to ride by, say three turns round the barrel, and when heaving-in is wanted the slack end is taken to the capstan in the usual way, but in this case there would be no necessity for having pawls on the capstan, and such lamentable accidents as that which happened lately in the *Great Eastern* would be rendered impossible.

Of course, when preferred, a chain wheel might be used in place of the turns on the barrel, but my faith would be in the turns round the barrel.

The arrangement of differential friction clutch, represented by the model, combines all the properties of a clutch proper for throwing the heaviest machinery into and out of gear with perfect ease, and without any shock whatever, with the properties of a friction cone for limiting the amount of strain that can be transmitted through it, and it is superior to any friction cone in this respect, that every time the clutch is thrown out of gear, the rubbing surfaces are changed so that they have no chance of setting fast, and while the clutch is either in or out of gear this limit may be regulated to a great nicety by the turning of a single bolt or nut.

The model of a reversible brake is mainly intended to represent a railway brake. The gripping action can be reversed by the moving of a lever. These brakes are supposed to act on a small wheel, say 10 or 12 inches in diameter on the carriage axles. By the use of this brake every wheel in the train might be scotched in a second by the guard, or the friction might be regulated as desired.

REGISTRATION AN IMPORTANT ELEMENT IN THE SAFETY OF SHIPS.*

By John Grantham, Esq., Member of Council.

[Read at the Eighth Session of the Institution of Naval Architects, April 13th, 1867; Joseph H. Ritchie, Esq., Member of Council, in the Chair.]

Many years of practical experience in the construction and working of ships and some years' connexion with the Board of Trade, of which I was one of the earliest surveyors appointed under the Acts which gave the Government control in the matter of the "Safety of Ships," have only served to strengthen the ever-growing conviction which I have long entertained, that the shipping interest is suffering from too much and too little interference. Too much, because it is subject to too many legal enactments, too many regulations, and too many surveys. Too little, because we have no certain channel by which supervision is exercised, or information as to the character of ships is obtained. Like many others who have held the same views, I have not clearly seen a remedy; a tender feeling towards existing institutions and laws, a fear of responsibility and of the trouble involved in striking out what might appear to be a new line of things, and the trammels of established usages, prevent us from taking a clear and comprehensive view of the vast questions which this subject embraces.

With this feeling weighing strongly on my mind, I ventured at the first meetings of our Institution to bring the matter before the members of the Council, and to ask for a committee of inquiry; but I stood alone, no one seconded the proposal. Thanks to the practical progress of our Institution, and to the clearer views which now obtain amongst us—thanks also to our President for having initiated the inquiry in which the Council have been for a whole year engaged—I have been permitted again to lay it before the members of the Council in a more matured form, and it is now likely to come fairly and clearly under the attention of Government, and it will rest very much with our Institution to guide this complicated and embarrassing subject to a more satisfactory issue. It is not the province of our Institution to initiate or take direct action in legislative questions: we may point out what we believe tends to promote or retard

* Received April 13th, 1867.

improvements in shipbuilding; but from this point, we can only act in our individual capacities, in furthering any steps the Government may deem it desirable to take.

It is the object of this Paper to point out, in a concise form, the difficulties in which the question is involved.

Since the last annual meetings, the members of the Council have had many anxious discussions upon the questions proposed for us in connexion with the "Safety of Ships," and we have to answer the question: What is the practical result of our deliberations, and how is effect to be given to the enquiries that have engaged so much of the time of the Council?

The free scope given to the discussion of subjects connected with the construction and management of ships is the special work of our Institution; but the effect of this would be lost, if the information, thus collected, could not be made available to the public. The subjects proposed for the consideration of the Council led us to deal with questions which are under the control of various departments, some of them regulated by legislative enactments, and all dealing more or less with the construction, equipment, and management of ships.

From personal communication with gentlemen in the varions departments, I learn that the present state of matters with respect to the laws and surveys of ships is considered very unsatisfactory, and nearly all agree that changes are required, and that one consistent plan, if practicable, would be most desirable. It happens that several of these great systems have risen up and have become very influential; but their not working in unison presents the real difficulty in dealing with the question; if it were possible to begin *de novo*, the way would be comparatively clear; and whether any uniform system that would be acceptable to all parties could be suggested, is a point worthy of the gravest consideration. The difficulty of finding an effectual remedy for all existing objections is admitted, but improvements arc practicable, and the necessity for some is everywhere felt. The number of surveyors employed, the variety of regulations to be followed, and of certificates to be obtained, and the bewilderment of the captains and owners are sometimes very great, and in the midst of all, most important matters are overlooked, and defects in minor details arc discovered when too late. If the whole could be placed under supervision of a more simple character, all acting in harmony, with experienced and competent inspecting officers, it is probable that greater safety would be ensured at a less sacrifice of time and expense.

The departments concerned in this question are—

The Board of Trade.

The Admiralty, in relation to the Post Office and Transport Service.

The East India Board, in relation to the Transport Service.
The Emigration Commissioners.
Lloyd's Registry of Shipping.
Registry of Iron Ships.
Shipowners' Association.

To make the question clear, it may be well to divide it, and consider it under three heads:—

1st.—Regulations or Bye-laws.
2nd.—Registration.
3rd.—Legislation.

Regulations or Bye-laws.—These consist of the regulations which are required in the various departments for the guidance of shipbuilders, owners, captains, and surveyors, and which may, from time to time, be altered or modified, so as to adapt them to the varied character, occupation, or progressive changes in the ships themselves, without requiring repeated changes in the legislative enactments.

Registration is a record of all ships built and worked under the regulations above named, with marks to denote the character and condition of such ships, and the service to which generally they are adapted.

Legislation is required to give powers to the different departments to enforce the regulations where necessary.

I propose to submit some general remarks upon the second of these heads. This appears to connect itself so essentially with the whole subject of the safety of ships, and, indeed, has its origin in that question, that we can only deal with it superficially, unless the previous question of registration be first maturely weighed.

It is to be desired, that all who are in any way concerned in carrying into effect the various systems of registration and surveying which have now become so burdensome and complicated, and, as a consequence, so frequently ineffectual, should regard this inquiry as of too much importance to admit of any partial consideration. We must approach the subject with one end only in view, namely, the advance of our national marine, both as regards safety of life and commercial prosperity.

These remarks are necessarily confined to merchant shipping; which, however, is the school, in this country, from which not only our best seamen, but also many great improvements in the navy, have had their origin.

We must also recollect that the subject of safety to passengers is rapidly concentrating all its interest in iron steamships: the only other class of passenger ships to which many lives are entrusted in this country is that for emigrants; but in this department a

rapid change is also taking place, and sailing ships are giving way to steamers. The passengers who entrust their lives in ships are not alone, however, to be considered. The crews and the cargoes require careful attention, from humane and economic considerations.

It is the great mission of our Institution to guide the public mind, and that we should assist one another as naval architects in avoiding the two extremes; so that, while advancing in the direction of increased speed, comfort, and economy, we may avoid *danger;* and on the other side, that we may avoid anything which tends to cramp or retard the progress of sound improvement, under a mistaken apprehension of running into danger.

As *registration* involves *regulations*, so regulations would be a dead letter, without registration, which is a public record of official inspection. I therefore repeat the opinion, that the registration of ships has a direct bearing on these questions, and would have a much more powerful influence, if properly understood and acted upon.

The great variety of regulations now in force, with reference to the safety of ships, requires simplification. Some of these have had their origin in bygone practices, or have been framed to supply unexpected contingencies, without regard to harmony of system.

The characteristics of these are as follows:—

The Board of Trade Surveys are compulsory, and the ships thus surveyed are registered; but the principal information conveyed is that such vessels are permitted to carry passengers for the following six months, or till again surveyed. No other vessels, but those carrying passengers, are to be found in this register.

The Custom House Register is compulsory, and is the only one that takes in vessels of every class that have to "clear out" for foreign or coasting voyages; but nothing in this is said about the character or condition of the ships. It is used as a record of tonnage, and the titles of ownery, with sufficient description to ensure their identity.

Emigration Surveys are regulated by Act of Parliament, but no public register is required.

Transport Surveys are upon the same principle; each of these departments has distinct surveyors.

Lloyd's Register.—The surveys in this department are not compulsory, but give the true character and condition of the ship. The system, however, does not meet all the requirements of the public. A large portion of the steamships

which now carry passengers and the most valuable cargoes are not in the register; neither are many other vessels which only carry cargoes.

Registry of Iron Ships is in reality a Liverpool Lloyd's Book. Distinct surveyors are employed, and it is conducted on the same principle as *Lloyd's Register*, but on a much more limited scale.

Here, then, are several distinct systems of official departments, surveyors, regulations, and registers, *but not one of them complete*—not one from which all the useful information required by the public can be obtained.

There should be, so far as is practicable, one comprehensive system of surveys and registration, so conducted, that all would feel it their interest to have their vessels included in it. Underwriters, shippers, passengers, and seamen should have a clear, simple and sure guide by which to regulate their judgment as to the craft into which they are about to trust their property or their persons; while the country at large should have the full benefit to be derived from the progress of practical science in engineering and shipbuilding. To comply with one or all of the registers now in use involves that a ship shall have a minimum of the requirements of each; and no deviation is allowed, except where compensation is made, which frequently amounts to some addition. Thus the vessel becomes burdened with excessive weight, which does not always give strength, and also with an excessive outfit.

I have on a former occasion pointed out the impossibility of making any regulations that shall adapt themselves to all cases; the strength of the materials, the proportions of the ships, the power employed, and their various forms and uses require, in nearly every vessel, some modification, if the best adaptation is aimed at. This is the work of the naval architect. The design, having been completed, has to be approved by the proper officers before being classed or registered. Contractors, when desired to build under special regulations, frequently do as they are told, and yield up their own judgment. Thus the intelligence of these men is not made available for advance in shipbuilding; and in a certain measure the owner also throws off his responsibility as to the quality and outfit of the ship. In other cases the alternative is adopted of avoiding the regulations, and consequently, the vessels are not classed or registered; a very large proportion of our iron steamships is thus excluded from those registers which specially refer to the character of the ship.

I am an advocate for having every vessel registered that has to carry passengers, or that has to be insured, and for having her general characteristics and condition noted. If, therefore, it is found that existing regulations are of a nature to prevent a considerable amount of tonnage from being registered, either the regulations should be altered, or

some new system of registration should be employed which should remove the difficulties. I have no predilections for any particular channel or institution through which this may be effected, provided the system itself shall be good.

A most able Paper was last year read at a Meeting of the Society of Arts by Mr. Thomas Gray, now Secretary to the Marine Department of the Board of Trade, taking a review of the effects of legislation as regards the safety of ships. He was followed by speeches from gentlemen well informed upon existing systems; and the whole is perhaps the best commentary that could be drawn up upon the subject.

Mr. Gray's object was to show that excessive legislation did not tend to increased safety, and nearly all the speakers, with varied modifications, agreed in these conclusions; all however, were equally agreed that legislation of some kind was necessary; but I could nowhere trace that any definite plan was proposed. Probably the difficulty felt by all on this point arises from viewing the question through the misty and confused medium of existing systems. On the other hand, violent and radical changes in old-established customs, and in matters involving such extensive operations, have to be approached with great caution. Salutary changes, however, are not hopeless. The Board of Trade regulations are of recent date, but are now firmly implanted in the country, and the principles, though not all the details, are considered sound.

The leading objects recommended for consideration are:—1st, to inquire whether the various legislative enactments and other regulations connected with shipping may not be embraced under one comprehensive system; 2ndly, whether regulations can be so framed, and surveys so conducted, as to make it no hardship for all vessels to be registered, and their character given, as is now only partially effected; 3rdly, to inquire whether all the departments should not be concentrated in one locality of each port, to afford facilities for the transaction of all business connected with surveys and registration.

No opinion is given in this Paper as to the merit of existing systems or rules; they may be the best that can be devised for the separate departments; any remarks that have been made on these are simply by way of illustration. The object is to shew, that the effect of these systems, taken as a whole, is bad; they do not conduce so far as they might do to the safety of ships, but may have, and frequently have had, the opposite tendency, and they are the cause of great trouble, expense, and confusion.

I am not a friend to excessive legislation, but I believe that the subject now before us is so important, that it becomes a grave question whether it does not warrant some simple and comprehensive Government interference; as, without it, any really effective measure seems hopeless.

DISCUSSION.

Mr. Reed: I think, Sir, after the preliminary statement which the President of the Institution made on Thursday, that Mr. Grantham's Paper will have its legitimate value, in that consideration of the subject which will ensue from the measures which are being taken; but, at the same time, Mr. Grantham's Paper is the result of very large experience gathered under very favourable circumstances; and I would suggest, if it meets with the approval of the other officers of the Institution, that the Paper of Mr. Grantham should be published in full among our abstracts, rather than be abbreviated in the forthcoming early publication which we propose, because it is full of suggestive matter, which I am sure we should all very much like to have the opportunity of studying carefully and leisurely. I hope, if the discussion is not prolonged, that Mr. Grantham will feel that it is rather owing to the force and clearness of his Paper, than to any want of appreciation of it, that we do not enter into any discussion.

Mr. Scott Russell: I beg also to bear my testimony, as far as my knowledge goes, to the value of Mr. Grantham's Paper. It is one of the most difficult problems with which the Legislature have to deal, whether to increase Government interference with private undertakings or to diminish it. It has always been an embarrassing question, and the fault perhaps of the present system of Government is, that it has interfered so as to take away private responsibility, and that it has not interfered far enough to ensure public safety. Probably the best kind of interference the Government can exercise is to take measures to provide that the public, including passengers, owners, and everybody, shall have the fullest possible information; and if the Legislature were to secure to the public the fullest possible information on the most authentic possible grounds, then, instead of this degree of interference tending to take responsibility off private individuals, it might be the means of throwing the responsibility entirely on those private individuals who, after all, have the best means of looking after the public safety, and who, in the end, are sure to have their interests identified with doing that which is best for the public. Perhaps the unfortunate thing at the present moment is that there are surveys, said to be Government surveys, which, from their very cursory nature, must be very often entirely without sound foundations—and that, being Government surveys, they lull the public into a confidence and a security for which there are no just grounds. Therefore, I am sure Mr. Grantham deserves the thanks of all of us for having put together in so lucid a form what the present state of the law is, and what are some of its most marked inconveniences and disadvantages; and should that Royal Commission which is spoken of be appointed, I have no doubt that Mr. Grantham's Paper would, by him, be brought before them, and would receive from them all the consideration to which it is so justly entitled.

Mr. Lamont: I am not a practical shipbuilder, but as a shipowner, I deprecate entirely the interference of Government on the paternal principle of taking care of us, and following out what Mr. Scott Russell has said, I think we have, as commercial men, to take care of this system of Custom House Registration, which I think was indicated by Mr. Grantham, and then Emigration interference, and then the Board of Trade interference, and then the Liverpool underwriters' system of looking after things. I think, with Mr. Scott Russell, that the shipowners and the commercial and practical men of this country ought to take care of this; and I think, also, that if you begin encouraging this paternal system of telling us "what we are to do," if we go so far, we do not know where the end of it may be. We shall be led

in leading strings. You ruin, I hold, the very first principles of business, if this system of Government interference, and telling us what to do, is carried out. It is quite proper that Lloyd's should say to the people who insure in Lloyd's—"We do not approve of this or that ship." It is quite right that they should say that, but only that—that they should say they do not approve of the ship—but they ought not to dictate, for it is always open to them to refuse, or to take, a risk. I think Mr. Grantham deserves thanks for the way in which he has brought forward this subject. At the same time, let us take care of that "paternal" system which will take the brains out of every man. The comprehensive system of registration, which Mr. Grantham has advocated, I object to, on the principle that every man should judge for himself as to what is right. I wish I could speak as Mr. Scott Russell can on a subject like this, but I wish to impress upon this meeting of intelligent, practical, and clever men, such as I see around me, the principle of avoiding above all things this system of "paternal" Government legislation.

Captain HENDERSON: I quite agree with what was said by the last speaker, that it is necessary to be careful of legislation. All I would say is, that what I have advocated for the last thirty years, has been very much in accordance with what Mr. Grantham has now put before us. We ought to be cautious. The question introduced is a very large one, and I quite agree with him that the better way is to let it be fully and fairly considered. I think the plan submitted by Mr. Grantham would admirably meet all that is required. We ought not to have Government interfering between the conflicting interests at work.

Mr. MERRIFIELD: I do not want to stop discussion, but the afternoon is drawing on, and we still have the elections of officers and of members.

The CHAIRMAN: The Paper just read is the last on the list.

Mr. CHARLES WIGRAM: It will be desirable to proceed with the election of officers at once.

ON WATER-TIGHT COMPARTMENTS IN IRON SHIPS, AS AFFORDING SECURITY AGAINST FOUNDERING.*

By F. K. Barnes, Esq., Mem. Council.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.

[Mr. Chairman and Gentlemen,—I should like to mention, in a few words, that I had no intention of contributing a Paper on any subject whatever to the Institution this year, until about a fortnight ago, when, on being informed that there was a lack of Professional Papers for the present Session, and on being pressed to write some Paper, I promised that if, in the short time remaining before the Session, I could manage to put together sufficient matter for a Paper, I would take as a subject the following, *viz.*, "*Water-tight Compartments in Iron Ships, as affording security against Foundering.*" Pressing official duties have, however, prevented me from writing a Paper to be read at this evening's meeting; but if I may be permitted, I will briefly describe the result of my consideration of the subject selected.

The substance of the following Paper was then given *extempore* by Mr. Barnes.]

There are several ways in which a ship may be divided into compartments by water-tight bulkheads; but three ways only have, as I am aware, been used either separately or collectively, *viz.*, by transverse vertical bulkheads, by longitudinal vertical bulkheads, and by horizontal bulkheads or flats, and to these three methods of division of a ship into water-tight compartments will my remarks in this Paper be confined.

In all cases I shall consider the several compartments to be quite empty, inasmuch as that is the most unfavourable supposition which can be made as regards the safety of the ship. I shall, moreover, neglect the thickness of the iron sides, and the volume of the iron frames, &c., that is, in all cases I shall assume that the volume of the iron contained in any injured compartment is absolutely equal to zero.

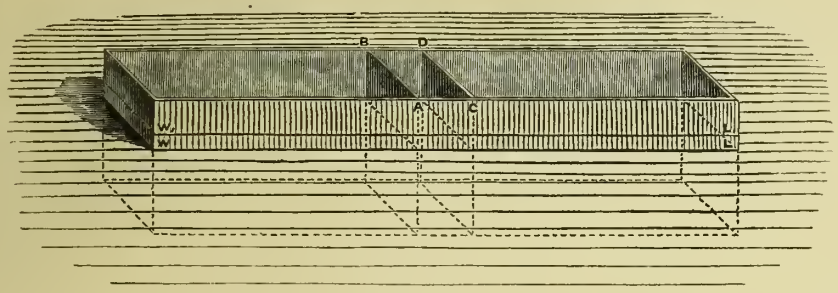
I shall in my remarks take very simple examples by way of illustration, and shall as a rule assume that the centre of gravity is, as is the case in nearly all ships, above the centre of buoyancy.

First, or common case, when a ship is divided into water-tight compartments by transverse vertical bulkheads.

* Received 5th December, 1867.

Let A B and C D (Fig. 1) represent two midship transverse vertical water-tight bulkheads in a ship of which the transverse vertical sections are all equal rectangles.

FIG. 1.



Let l = length of the ship.

b = its breadth.

d = draught of water to line W L.

$\frac{l}{n}$ = portion of the length A C or B D between the bulkheads.

Now, suppose the compartment between the bulkheads to become injured, and the water-level inside the compartment to become co-incident with that outside of it, and let $W_1 L_1$ represent the new water-line parallel to W L suppose.

Let x = draught of water to line $W_1 L_1$.

Then the original volume of displacement = $l\ b\ d$.

After the compartment is injured the volume of displacement = $l\ (1 - \frac{1}{n})\ b\ x = l\ b\ d$.

$$\therefore x = \frac{d}{1 - \frac{1}{n}}$$

The centre of buoyancy from the bottom of the keel before compartment is injured = $\frac{d}{2}$

Ditto after injury:

$$= \frac{x}{2} = \frac{\frac{d}{2}}{1 - \frac{1}{n}}$$

Metacentre above the centre of buoyancy before the compartment is injured:

$$= \frac{\frac{2}{3}\, l\, (\frac{b}{2})^3}{l\ b\ d}$$

$$= \frac{1}{12}\, \frac{b^2}{d}$$

Ditto after injury to compartment:

$$= \frac{\frac{2}{3}\, l\, (1 - \frac{1}{n})\, (\frac{b}{2})^3}{l\ b\ d}$$

$$= \frac{1}{12}\, \frac{b^2}{d}\, (1 - \tfrac{1}{n})$$

Metacentre above the bottom of the ship before the compartment is injured:

$$= \frac{d}{2} + \frac{1}{12}\, \frac{b^2}{d}$$

Ditto after the compartment is injured:

$$= \frac{\frac{d}{2}}{1-\frac{1}{n}} + \frac{1}{12}\,\frac{b^2}{d}\,(1-\tfrac{1}{n})$$

On making $b = d$, and $n = 100$, 10, 4, and 2 respectively,
$b = 2\,d$, and $n = 100$, 10, 4, and 2 respectively,
$b = 3\,d$, and $n = 100$, 10, 4, and 2 respectively,
$b = 4\,d$, and $n = 100$, 10, 4, and 2 respectively,
the following values, contained in the accompanying Table, of the height of the metacentre above the lower edge of the keel, before and after the injury to the compartment, will be obtained:—

TRANSVERSE BULKHEADS.

Value of b.	Value of n.	Metacentre above Centre of Buoyancy.		Metacentre above Keel.	
		Before the Compartment fills.	After the Compartment fills.	Before the Compartment fills.	After the Compartment fills.
d	100	$\cdot08\dot{3}\cdot d$	$\cdot0825\cdot d$	$\cdot58\dot{3}\cdot d$	$\cdot5875\cdot d$
d	10	$\cdot08\dot{3}\cdot d$	$\cdot075\cdot d$	$\cdot58\dot{3}\cdot d$	$\cdot630\dot{5}\cdot d$
d	4	$\cdot08\dot{3}\cdot d$	$\cdot0625\cdot d$	$\cdot58\dot{3}\cdot d$	$\cdot7292\cdot d$
d	2	$\cdot08\dot{3}\cdot d$	$\cdot041\dot{6}\cdot d$	$\cdot58\dot{3}\cdot d$	$1\cdot041\dot{6}\cdot d$
$2\,d$	100	$\cdot\dot{3}\cdot d$	$\cdot3300\cdot d$	$\cdot8\dot{3}\cdot d$	$\cdot835\cdot d$
$2\,d$	10	$\cdot\dot{3}\cdot d$	$\cdot3000\cdot d$	$\cdot8\dot{3}\cdot d$	$\cdot8\dot{5}\cdot d$
$2\,d$	4	$\cdot\dot{3}\cdot d$	$\cdot250\cdot d$	$\cdot8\dot{3}\cdot d$	$\cdot91\dot{6}\cdot d$
$2\,d$	2	$\cdot\dot{3}\cdot d$	$\cdot16\dot{6}\cdot d$	$\cdot8\dot{3}\cdot d$	$1\cdot16\dot{6}\cdot d$
$3\,d$	100	$\cdot75\,d$	$\cdot7425\,d$	$1\cdot25\,d$	$1\cdot2475\,d$
$3\,d$	10	$\cdot75\,d$	$\cdot675\,d$	$1\cdot25\,d$	$1\cdot230\,d$
$3\,d$	4	$\cdot75\,d$	$\cdot5625\,d$	$1\cdot25\,d$	$1\cdot2291\,d$
$3\,d$	2	$\cdot75\,d$	$\cdot375\,d$	$1\cdot25\,d$	$1\cdot375\,d$
$4\,d$	100	$1\cdot\dot{3}\cdot d$	$1\cdot320\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot825\cdot d$
$4\,d$	10	$1\cdot\dot{3}\cdot d$	$1\cdot200\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot75\dot{5}\cdot d$
$4\,d$	4	$1\cdot\dot{3}\cdot d$	$1\cdot000\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot6\dot{6}\cdot d$
$4\,d$	2	$1\cdot\dot{3}\cdot d$	$\cdot\dot{6}\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot6\dot{6}\cdot d$

From an examination of the Table it will be seen, that in all cases, when the breadth is equal to the depth and to twice the depth, the height of the metacentre above the lower edge of the keel is greater after the compartment is injured than it was before; and, as already stated, we assume that the volume of the iron forming the sides of the compartment is equal to zero, and that when the compartment is empty the centre of gravity of the ship remains unaltered: consequently, also the stability of the ship is in all these cases greater after the compartment is injured than it was before. It follows, therefore, that if sufficient free-board be given to such ships to admit of their immersion being increased to the extent due to the volume of any one or more of its compartments, they will be quite safe when the said compartments are injured. It also follows that ships of the above form and relative proportions would be lost by going down bodily in the water and losing their free-board, and not from losing their stability and turning over.

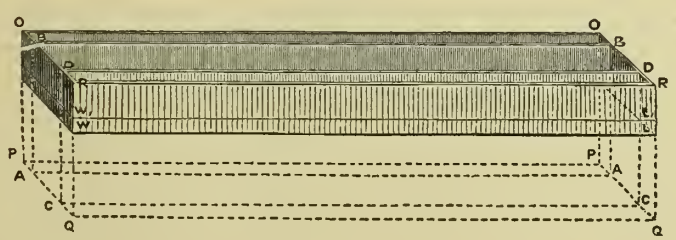
The same remark is practically applicable to the case in which the breadth is equal to three times the depth.

Where the breadth is equal to four times the depth, the metacentre falls slightly between the limits taken; but it manifestly rises again as the bulkheads are placed nearer to the extremities of the ship.

As the breadth increases above this in proportion to the depth, the relative depression of the metacentre by injury to the compartments will be increased; but it must be borne in mind that in such cases the metacentre, before injury to the compartments, would be exceedingly high.

The second case is that of an iron ship divided into water-tight compartments by longitudinal vertical bulkheads.

FIG. 2.



Let O P Q R (Fig. 2) represent the transverse section of a ship of which the length is l, its breadth b, and its draught of water to line W L equal to d. Let A B and C D represent

two vertical longitudinal water-tight bulkheads, each a distance $\frac{b}{n}$ from the ship's side and assume that a communication is made from side to side, so that when the compartment on one side is filled, the compartment on the other side is also filled.

Then, as before, the volume of displacement $= l\ b\ d$.

If $x =$ draught of water after both compartments have become filled with water, then the displacement

$$= l\ x\ (b - \tfrac{2b}{n}) = lbx\ (1 - \tfrac{2}{n})$$

$$= l\ b\ d$$

$$\therefore x = \frac{l\ b\ d}{l\ b\ (1 - \frac{2}{n})} = \frac{d}{1 - \frac{2}{n}}$$

The centre of buoyancy above the bottom of the vessel before the compartments are filled $= \frac{d}{2}$

Ditto after they are filled:

$$= \frac{x}{2} = \frac{d}{2\ (1 - \frac{2}{n})}$$

Metacentre above the centre of buoyancy before the compartments are filled:

$$= \frac{1}{12}\ \frac{b^2}{d}$$

Ditto after:

$$= \frac{\frac{2}{3}\ l\ (\frac{b}{2} - \frac{b}{n})^3}{l\ b\ d} = \frac{2}{3}\ \frac{b^2}{d}\ (\tfrac{1}{2} - \tfrac{1}{n})^3$$

$\therefore$ Metacentre above the bottom of the vessel before the compartments are filled:

$$= \frac{d}{2} + \frac{1}{12}\ \frac{b^2}{d}$$

Ditto after:

$$= \frac{\frac{d}{2}}{1 - \frac{2}{n}} + \frac{2}{3}\ \frac{b^2}{d}\ (\tfrac{1}{2} - \tfrac{1}{n})^3$$

On making $b = d$, and $n = 100$, 10, 4, and 2 respectively,

$b = 2\ d$, and $n = 100$, 10, 4, and 2 respectively,

$b = 4\ d$, and $n = 100$, 10, 4, and 2 respectively,

the following values, shown in the accompanying Table, will be found, giving the height of the metacentre above the bottom of the vessel before and after the injury to the compartments:—

Vertical Longitudinal Bulkheads.					
Values of b.	Values of n.	Metacentre above Centre of Buoyancy.		Metacentre above Keel.	
		Before the Compartments fill.	After the Compartments fill.	Before the Compartments fill.	After the Compartments fill.
d	100	$\cdot08\dot{3}\cdot d$	$\cdot0784\cdot d$	$\cdot58\dot{3}\cdot d$	$\cdot5886\cdot d$
d	10	$\cdot08\dot{3}\cdot d$	$\cdot042\dot{6}\cdot d$	$\cdot58\dot{3}\cdot d$	$\cdot6676\cdot d$
d	4	$\cdot08\dot{3}\cdot d$	$\cdot0104\cdot d$	$\cdot583\cdot d$	$1\cdot0104\cdot d$
d	2	$\cdot08\dot{3}\cdot d$	$\cdot0000$	$\cdot583\cdot d$	∞
$2\,d$	100	$\cdot\dot{3}\cdot d$	$\cdot3136\cdot d$	$\cdot8\dot{3}\cdot d$	$\cdot8238\cdot d$
$2\,d$	10	$\cdot\dot{3}\cdot d$	$\cdot170\dot{6}\cdot d$	$\cdot8\dot{3}\cdot d$	$\cdot7956\cdot d$
$2\,d$	4	$\cdot3\cdot d$	$\cdot0416\cdot d$	$\cdot8\dot{3}\cdot d$	$1\cdot0416\cdot d$
$2\,d$	2	$\cdot3\cdot d$	$\cdot0000$	$\cdot8\dot{3}\cdot d$	∞
$4\,d$	100	$1\cdot\dot{3}\cdot d$	$1\cdot2544\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot7646\cdot d$
$4\,d$	10	$1\cdot\dot{3}\cdot d$	$\cdot6826\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot3076\cdot d$
$4\,d$	4	$1\cdot\dot{3}\cdot d$	$\cdot166\dot{6}\cdot d$	$1\cdot8\dot{3}\cdot d$	$1\cdot16\dot{6}\cdot d$
$4\,d$	2	$1\cdot\dot{3}\cdot d$	$\cdot0000$	$1\cdot8\dot{3}\cdot d$	∞

It will be seen from the Table, that in all cases given, where the breadth is equal to the depth, the height of the metacentre above the bottom of the vessel is greater after the compartments are filled than it was before; and since, from the suppositions we have made, the centre of gravity of the ship itself is unaltered, the ship, if stable before the compartments are filled, will be more stable after they are filled.

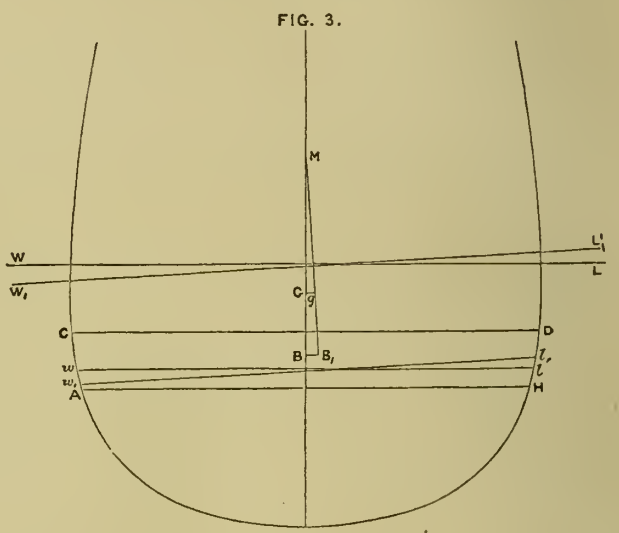
When the breadth is equal to twice the draught of water, the metacentre descends when the vertical longitudinal bulkhead is very close to the ship's side, and it reaches its lowest position when the bulkheads are fixed somewhere between one-fourth and one-tenth of the ship's breadth from the ship's side. From this position, as the bulkheads are placed nearer to the middle line, the metacentre continually rises as they approach the middle line. The same remarks apply when the breadth is equal to four times the draught of water; but the lowest position of the metacentre will not be reached until the bulkheads are relatively much nearer to the middle line than when the breadth of the ship is equal to twice the draught of water.

In my remarks I have only considered the case where the compartments on both sides of the ship are injured; but the case when the compartments on one side of the ship only are damaged is worthy of special consideration.

The third method in which a ship may be divided into water-tight compartments is by horizontal bulkheads or flats, each compartment being made to communicate with the upper deck of the ship by means of small water-tight trunks.

Let A H C D, Fig. 3, represent a water-tight compartment between the two water-tight flats, A H and C D.

FIG. 3.



To take the simplest case first, let us suppose that a compartment between any two horizontal flats becomes suddenly filled with water. The effect of this will be exactly the same as if a weight, equal to that of the water in the injured compartment, had been put on board, and consequently the vessel sinks to a deeper line.

Now, I have shown elsewhere that when a weight is placed on board of a ship which sinks her to another water-line, the form of which is similar, and its area equal to the original water-line, according as the centre of gravity of the weight placed on board is situated at the same height as, above or below, the centre of gravity of the additional displacement due to the weight placed on board, so the stability of the ship remains unaltered, is diminished, or is increased. It is easy to see, therefore, that considering the water in the injured compartment as the weight added, its centre of gravity can never be higher than the centre of gravity of the additional displacement. The worst case which could occur is that in which a water-tight deck is placed just below the original water-line, and the compartment above that deck becomes filled with water; in which case the new water-line will be situated just above the next water-tight deck, and the centre of gravity of the weight added is only a small distance below that of the additional displacement. In this case it is clear, from the considerations above named, that the stability is increased to a small extent only.

If any of the lower compartments of such a ship were to become filled, it is evident that the stability would always be greater after the compartment was filled than it was

before, and would increase with the size of the compartment, and also with the distance of its centre of gravity below the water.

The case now remaining to be dealt with, and which will require special treatment, is that in which a ship, divided into water-tight compartments by horizontal flats, has one of these compartments only slightly injured.

Let W L, Fig. 3, represent the water-line of a ship which has a small quantity of water in the water-tight compartment A H C D, which covers the entire surface of the bottom of the compartment to a small depth only. Let G be the centre of gravity of the ship after the small quantity of water is on the flat A H, and let B represent the corresponding centre of buoyancy.

Now, let a very small inclination be given to the ship, so that the centre of buoyancy shall move from B to B_1, and if M be the point in which the vertical through B_1 cuts the original vertical B M, then, when the inclination is exceedingly small, M is the metacentre and the height of the metacentre above the centre of buoyancy, or

$$\text{B M is} = \tfrac{2}{3}\int \frac{y^3 dx}{\text{W}}$$

where y represents the half ordinates of the water section W L, and W the volume of the displacement. Through G (Fig. 4), the centre of gravity of the ship, draw Gg parallel to B B_1, cutting the vertical B_1 M in g.

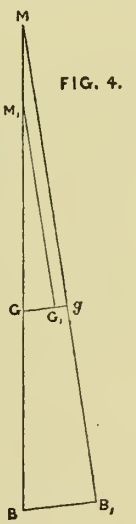


FIG. 4.

Now, the water in the damaged compartments will have its surface parallel to the inclined water-line $W_1 L_1$, and the centre of gravity of the water in the compartment having shifted towards the immersed side, will cause the centre of gravity of the ship to travel nearly in a line Gg parallel to B B_1 to a point G_1. Through G_1 draw $G_1 M_1$ vertical, cutting the original vertical through the centres of gravity and buoyancy in the point M_1, suppose when the inclination is exceedingly small, then clearly

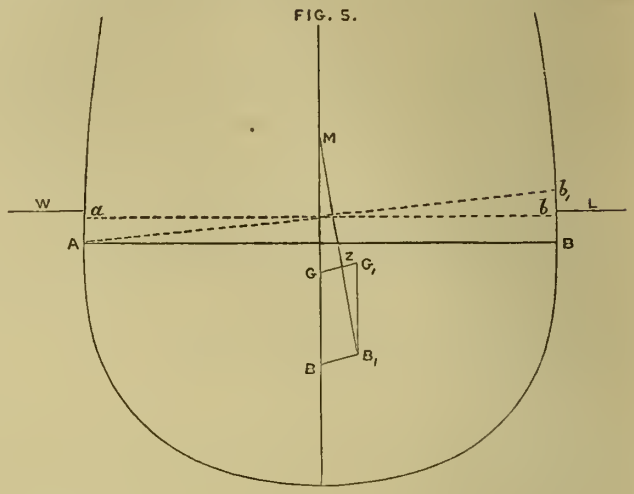
$$\text{G M}_1 = \tfrac{2}{3}\int \frac{y_1{}^3 dx}{\text{W}}$$

where y_1 represents the half ordinates of the water section $w\ l$ (Fig. 3) in the injured compartment.

It is evident from an inspection of the figure that when G M_1 is less than G M, or when $\frac{2}{3}\int \frac{^3y_1\, dx}{\text{W}}$ is less than $\frac{2}{3}\int \frac{y^3 dx}{\text{W}}$ − B G, the ship will float safely. If G M_1 is equal to G M, the equilibrium of the ship will be indifferent; and when G M_1 is greater than G M, the ship is unstable.

To illustrate the extreme case, let W L, Fig. 5, represent the water-line of a ship with a water-tight deck, A B, fitted in her just below the water-line before the ship is damaged. When the compartment above A B is slightly damaged, and fills until *a b* becomes the surface of the water therein, the area of the surface of the water *a b* may be taken as being equal and similar to the load water section.

FIG. 5.



When an inclination is given to the ship, and B_1 becomes the new centre of buoyancy, draw G G_1 parallel and equal to B B_1; then because the wedge of water moved inside of the vessel is similar and equal to that outside, it is evident that the point G_1 is the new centre of gravity of the ship. And because B_1 G_1 is parallel to B G, the point G_1 must be situated outside of the vertical B_1 M drawn through the new centre of buoyancy B_1. From G_1 draw G_1 Z perpendicular on B_1 M_1. Then W × G_1 Z is the moment of the couple tending to upset the ship,

$$= W \times B\,G \sin I, \text{ suppose (where I is the inclination).}$$

When the ship has reached such an inclination as will bring the surface of the water in the damaged compartment coincident with the flat at the ship's side, it is clear that the upsetting force is greater than for any other position between that and the upright, and that with further inclination, owing to the moment of inertia of the plane of flotation exceeding that of the plane of the water's surface in the compartment, the moment of the upsetting force will diminish; but it is clear that the position of equilibrium will not be reached until a much larger inclination of the ship has taken place.

From what has now been stated, it is evident that when the upper surface of a horizontal flat, situated at the load water section in a ship of the usual form (of which the centre of gravity is above the centre of buoyancy), becomes covered only to a slight depth with water, the ship will not swim with its longitudinal diametral plane vertical, since the equilibrium of the ship when that plane is vertical is one of instability.

The same is also true of a ship with its sides vertical throughout, at whatever height the water-tight flat, which is covered with water, may be situated, provided the centre of gravity is above the centre of buoyancy; and more generally still when, under similar circumstances, the moment of inertia of the plane of the surface of water on any

deck about a longitudinal horizontal axis is equal to or greater than that of the load water section about its longitudinal axis.

Such ships, in the condition above described, would generally have two positions of stable equilibrium, one on each side of what is the upright position before the water is on the deck; and the inclination of the two positions of equilibrium to the upright position would increase with the quantity of water on the deck.

In the extreme case we have assumed, of the moment of inertia of the water surface inside of the damaged compartment being equal to that of the load water section, it is clear that if the centre of gravity of the ship were situated below the centre of buoyancy, or G M greater than B M, the upright position would be one of stable equilibrium. If the moment of inertia of the surface of the water on any deck be greater than that of the load water section, the upright position may be one of instability, when the centre of gravity is below the centre of buoyancy, as G M_1 (Fig. 3) may be greater than B M.

DISCUSSION.*

Mr. MERRIFIELD: What Mr. Barnes has shown us is very interesting, but there appeared to me to be one or two points which I did not quite understand. I am sure he will be able to explain them satisfactorily, because we know he is not given to make mistakes, and I am sure also he will understand that I am only asking for explanations which will be useful, perhaps, to the Meeting, and certainly, I hope, to some of my pupils. I did not quite understand how the metacentre should rise by the flooding of a single vertical compartment, and for this reason:—taking the case of a ship with a uniform transverse section, then we know that unless the half-breadth increases as she sinks, the metacentre—the expression for the height of the metacentre above the centre of buoyancy—contains the displacement in the denominator. Therefore, if the displacement increases, other things remaining the same, the distance between the metacentre and the centre of buoyancy decreases. In point of fact, if we could call B the centre of buoyancy, and μ the metacentre, the common expression for that is—

$$B\mu = \frac{2}{3}\frac{(\frac{1}{2}\text{ breadth})^3}{\text{displacement.}}$$

Now, unless the centre of displacement rises, or unless the half-breadth increases—and this is the very point upon which I wish to get Mr. Barnes's explanation—I do not see how it can increase. If, of course, as is the case in many vessels, the half-breadth increases on the average so as to make the sum of the cubes increase, then I can understand the thing distinctly; but otherwise I cannot, because, taking the ordinary

* It must be borne in mind in reading the Discussion, that the subject of the Paper was put before the Meeting in mere outline, and the Gentlemen who took part in the Discussion had not, therefore, so good an opportunity of following the author of the Paper as is afforded by the reading of a carefully written Paper.—F. K. B.

form of a ship, if you let water into a vertical compartment, you do not raise the centre of buoyancy by doing so, but, on the contrary, by a very slight quantity you decrease it. There are other questions connected with stability and rolling which affect to a very great extent the question of a vessel sinking. A great deal that has to do with the question of vessels upsetting is this:—it is quite true that they have a small hole that lets the water in in all cases, otherwise they go down directly. There is no doubt about that, but generally it is too small to affect the stability of the vessel, and although the decks are much less tight in merchant vessels than they are in ships of war, yet still the water has not quite free play inside them, and they are more or less of a cellular character, and that is proved by the fact that when a vessel is going down her decks generally blow up, and consequently, the water has very much the effect of water-ballast, in so far as the upsetting is concerned, and that is one of the principal reasons why vessels do not capsize before foundering. With regard to the question of displaced water, that is a very easy question. As far as I recollect, it is simply a question of subtracting the moments of the two stabilities, the moment of the vessel without the water, and the moment of the enclosed water without the vessel. Therefore, the simplicity of it is, I fancy, pretty great on that principle. I shall be very glad of Mr. Barnes's explanation of how the metacentre rises in this case.

Mr. George Barber (Chief Shipwright Surveyor to the Board of Trade): There is one question, Sir, which I should like to put to Mr. Barnes. I believe that his Paper, which is very valuable in a theoretical point of view, would also be very valuable in a practical point of view, if he would tell us, or give us some idea—those of us who have not had the pleasure of hearing or of reading his first Paper—at what height these decks should be placed in order to ensure the safety of a vessel if any one of her compartments should become filled? There are now no legislative enactments for compelling merchant vessels to have water-tight bulkheads; but, although those enactments have been repealed, it is the desire of most merchant owners and shipbuilders so to divide their ships, that in the event of any of the compartments filling, those ships will remain afloat; and it will be of great service to them, as well as to others who take an interest in these matters, if Mr. Barnes can give us some idea, or some rule, or some formula by which we can tell, with some pretty near approach to certainty, at what height we should place these horizontal bulkheads, so that in the event of any of the compartments filling our ships would be safe. I see my friend Mr. Scott here, and he will corroborate me when I say, that the ships he has built have been loaded—not with water—I do not know that any one of them has filled, but with cargo to such a depth, that it has often been a wonder to us that they have not gone down; and I have often said,—"I wonder now, after that ship has been loaded down, how much deeper she could be put before she would sink?" I have listened with great interest to Mr. Barnes's Paper to-night, and I think if he could give us some idea at what height from the keel a water-tight deck should be fixed, or a series of water-tight decks should be placed, so that in the event of a vessel being struck by collision, or by striking on a rock herself, those compartments would ensure her safety, he would do a great service to the mercantile marine of this country, seeing that we are now left entirely to the skill and the forethought of shipbuilders and shipowners, who are not bound by legislative enactments in the construction of vessels for the merchant service. I beg pardon for offering these remarks. I am not a Member of this Institution. I am only here by invitation, and I do not really know whether I have done right in speaking, or whether I even have the liberty to speak.

The Chairman (Sir Edward Belcher): You are quite right, Sir. Before Mr. Barnes replies, I do

not know whether it will be competent to me to make an observation; but I should like to say that I happen to be the only person, I believe, in Her Majesty's navy who ever had *carte blanche* to do as he pleased with his ships, and I have fitted five of Her Majesty's ships with air-tight bulkheads successfully. The *Terror*, the vessel which was lost with Sir John Franklin, had the whole of her heel and part of her stern-post knocked away, and you might have caught cod in her after-hold during the whole of her passage home; in fact, the after-hold was filled with water, but the aft compartments kept her perfectly safe. I have drawn out here the mode in which I fitted the *Erebus*, the *Terror*, the *Etna*, the *Samarang*, and the *Assistance*. In the three first, being bombs, the lower part of the bulkhead rested on false keelsons, and I preserved the side ones to enable me to ventilate the ship. Then a deck was laid across and caulked, and was as clean as the upper deck of a ship. On that the tanks were placed; the bulkheads were carried on from here, the verticals, and made perfectly tight. The lower deck opened by hatches from above, and we were enabled to stow vertically into these two wings, which you cannot do satisfactorily from a hold; consequently, all the coals, which only had a specific gravity of 73, were stowed in each of those quarter sections. That drove these bulkheads still more against the iron tanks, and if any accident had happened to the ship down as low as her floor-heads it would not have mattered at all, the water could not have got into the ship. I do not see why—I cannot see that there is any reason why—in merchant vessels similar longitudinal air-tight bulkheads should not be carried fore and aft the vessel to above the transverse ones. There is another point. Where you put goods into a ship, and those goods can be placed in anything like packages that will bear any weight of any other portion of the cargo to be placed against them, if you were to cover those with very rough canvas, and then cover that with brown paper, it would be perfectly impervious to any sea that came into the hold, and probably if the ship filled it would save the ship. In the Chinese junks, they are divided exactly in that way into tanks, and each merchant has a tank to himself; his goods are stowed in that tank, and they are hermetically sealed, and consequently if the water makes a breach over the vessel, all these tanks are perfectly secure, and the vessel is not lost.

Mr. Galloway: It was my lot several years ago to be in a screw-steamer off the Cape of Good Hope in very rough weather. This steamer was built in compartments. One of the compartments was filled with water. We observed this very specially, that when the vessel did roll she was some time before she took to roll again, and so, the weight of the water being carried with the roll of the vessel, tended very much to prevent that vessel righting herself in her proper position. I hold that though we may build vessels in compartments, and though we may continue doing it up, as it were, to the deck, that plan, generally speaking, would be attended with considerable disadvantages. I maintain that there is a better plan than that—a plan of universal application—which will give floating power far beyond the floating power which can be obtained by any divisional arrangement. I submit that if that plan does succeed, it will be of paramount importance to the nation, and specially to the Admiralty, for next in importance to the perfection of the penetration of shot, will be the absolute necessity and importance of giving additional floating power. Without occupying your time further, I at once state my plan to be this:—You can, underneath the fore beams of vessels, generally affix pipes longitudinally, and the reverse as between the beams. You can also affix pipes along the ceiling on either side of the ship. You can also render those pipes, by affixing within them valves, applicable for ventilating your ship thoroughly fore and aft through the different compartments. I submit that that arrangement is practicable, is easy of application, and the fact is, in my opinion, that the sooner it is adopted the better.

Mr. Rawson: The question which has been put by Mr. Merrifield appears to me on the face of it to be a very pertinent one, and much to the purpose. The formula which he has placed upon the board is a well-known formula, and is quite accurate; and from that formula he wishes to know how the metacentre can rise, observing that the half-breadth in the two cases remains the same, and the denominator, that is the displacement, is increased. That really does seem to be a sort of puzzle, that the numerator of a fraction should remain the same, the denominator be increased, and still the metacentre be raised to a greater distance from the centre of buoyancy. Still I think, notwithstanding that, that my friend Mr. Barnes is correct in his statement when he says that the metacentre rises—if I understand him correctly. Now, supposing that the half-breadth remained the same in both cases, and an additional weight to be placed in the vessel, it is evident that the water-line of that vessel would be raised slightly. At the same time the centre of buoyancy will be raised. Now, the dimensions of the ship will shew whether the metacentre will rise more than the centre of gravity, or whether it will rise the same. If it rises exactly the same, there is no difference between the ratio of the half-breadth cube put into Simpson's Rule, and the increased volume of displacement—a phrase which I am sure Mr. Merrifield understands perfectly well. If that remains the same, then the metacentre will rise quite as much as the centre of buoyancy. In the case, I presume, that Mr. Barnes has advanced, you will see that if the weight which is put into the vessel depresses the vessel an inch, the centre of buoyancy will perhaps rise half an inch. I am speaking now in round numbers. Of course that remains to be verified. It will rise slightly. The centre of buoyancy must rise if the centre of displacement is increased. Well, that is a question for calculation, but the same distance may remain between the centre of buoyancy and the metacentre, and still both those points may be moved by the additional weight which is placed in the ship. In my opinion Mr. Barnes is perfectly correct, and so is Mr. Merrifield, if I understand the question properly. I think there is no doubt about the centre of buoyancy being raised if there is an extra weight put in, and there is more displacement. In both cases the two points must rise. It is a question of some difficulty, and depends upon the dimensions, which rises the most.

Mr. Merrifield: Does not the centre of buoyancy rise with reference to the keel of the ship, but fall with reference to the water-line at the increased displacement?

Mr. Rawson: I do not quite understand the question.

Mr. Merrifield: Does not the centre of buoyancy rise—supposing you increase the displacement—does not the centre of buoyancy rise with reference to the keel of the ship, and fall with reference to the actual water-line of the displacement?

Mr. Rawson: I do not know. If there is an increased body of water displaced, the centre of gravity must rise.

Mr. Welch: I beg to corroborate the view taken of this subject by Mr. Rawson. I know the case of a coal vessel which went 4 inches deeper in the water. I found the relative difference between the centre of buoyancy and the metacentre, and I found as he stated, that the metacentre was raised but slightly, and the centre of buoyancy came up almost in the same proportion, though not exactly.

Mr. Barnes: I will briefly reply to the Gentlemen who have spoken, beginning with Mr. Merrifield. First let us ascertain what would happen when a compartment between two transverse vertical bulkheads becomes filled. It is easy to see that the buoyancy lost at the injured compartment below the original

water-line is transposed to the uninjured parts of the ship, outside of the bulkheads above the original water-line, and by this movement the centre of buoyancy must evidently have gone up considerably. Supposing the ship to be of an uniform rectangular form throughout, the distance of the centre of buoyancy from the lower edge of keel in the new position would be just half the distance from the free surface to the lower side of the keel, and the centre of buoyancy in the original position half the distance to the original water-line, so that evidently the centre of buoyancy will have gone up through a distance equal to one half the distance between the two water-lines. The metacentre, as Mr. Merrifield has very correctly shown, will of course fall with reference to the centre of buoyancy; that is to say, the distance from the centre of buoyancy to the metacentre must always decrease in consequence of the decrease in the moment of inertia of the load water section and the displacement remaining the same, but as the centre of buoyancy rises, it is evident that if the centre of buoyancy rises more than the distance from the metacentre diminishes, the metacentre will be higher in the ship, or at a greater distance from the keel after the compartment is damaged than it was before. I can make myself plain in the following way:—Let us imagine that we have a very high ship, with fine ends and extremely light topsides, and suppose she has only two transverse vertical bulkheads placed near the extremities. If the ship be damaged between the bulkheads she will sink in the water until the buoyancy at the two ends above the original water-line is equal to that lost by the filling of the compartment. It is evident, in the extreme case imagined, that the centre of buoyancy is situated at a very great height above the bottom of the keel, the height increasing as the distance of the bulkheads from the extremities is diminished, and the centre of buoyancy may evidently be considerably higher than the original metacentre.

Mr. Merrifield: From the keel?

Mr. Barnes: Yes; and the new metacentre is (if only a small distance) above this new centre of buoyancy, and since, from the suppositions we have made throughout, the centre of gravity remains at the same height above the keel as before the compartments were injured, the stability of the ship is clearly greater after the injury than it was before. With regard to the remark made by Mr. Rawson, I think he looked at the question in rather a different way. I do not doubt that what Mr. Rawson says is perfectly true, but then it is rather a different case from that which I was considering. What I said in speaking of water-tight decks was, that if you could fill any water-tight space, or any compartment of the form supposed—actually fill it—then there is no danger whatever to the ship, provided there is free-board sufficient to give buoyancy equal to the volume of the compartment filled when the ship founders; she would not go over, but sink down, if the compartments were absolutely filled with water. There is no doubt on this point, whatever be the form of the ship, as the case admits of a general proof. When however, the quantity of water is small, then the case is very different; in a ship with a water-tight deck just below the water-line, if a small hole be made in the ship's side immediately above it, water will be admitted into the compartment, and it is possible that while the compartment is filling, the ship may go over; whereas, if the compartment were to fill, the ship would not go over, but settle down evenly and be safe if the free-board were sufficient to meet extra buoyancy required, which is equal to the volume of the compartment.

The Chairman: I think we have to thank Mr. Barnes for bringing this subject before us. It is a very good thing to get a man to write a Paper, but if he will not write a Paper, the next best thing is to get him here to speak. We shall be sure to get his Paper by-and-by, because what he has said will be

brought to him in type, and he will be asked to correct it. I am sure you will agree with me in giving him our thanks.

Mr. BARNES: I should be glad to know, Sir, whether I am expected to supply a Paper in writing?

The CHAIRMAN: When the letter-press is sent to you, you can correct, and add to it.

Mr. BARNES: Of course it is a very important subject.

The CHAIRMAN: If there has been any dispute you are not permitted to put in other matter which you have not controverted; but as there is no dispute upon this question, I think you would be fully authorised in filling up any printed matter.

Mr. BARNES: I shall be very happy to do so.

DESCRIPTION AND USE OF A WAVE-TRACER AND A ROLL-TRACER.*

By Admiral E. Paris, Associate.

[Read at the Eighth Session of the Institution of Naval Architects, April 12th, 1867; Vice-Admiral Sir Edward Belcher, K.C.B., Assoc. Mem. Council, in the Chair.]

1.—*The Wave-Tracer.*

The various alterations lately made in naval construction have produced very remarkable improvements. Vessels of such high speed and strong build as those of the present day, have never, until now, appeared upon the seas. It must, however, be conceded that one general result has been an increase in the rolling motion, sufficiently marked to be prejudicial. If, by the lengthening of their hull, the steam packets have acquired remarkable speed, they roll more than the old sailing ships; and on the other hand, if the new ships of war are made invulnerable by their sheathing of heavy iron plates, they also roll much more than vessels of the old construction. Iron-clads are nothing else than old men-of-war, whose upper deck batteries, with part of their masts and rigging, are removed, to be replaced by an equal weight on the sides, close to the water-level. The position of the weights has been much more changed than their form, and yet they roll in an unusual manner. The packets, however, have only been lengthened, and whatever the difference may be, the modern changes in the mode of building ships have produced in both kinds an increase of rolling, which is generally acknowledged. Still, it must be confessed that this acknowledgment is based only on personal opinions. The general consent of opinion warrants its correctness as to the existence of the phenomenon, but fails to give its measure, and still more its cause. These things remain unknown, and if we follow our previous practice, it is because nothing has appeared to throw light upon this question.

Although the Institution of Naval Architects has lately begun to study the question of the rolling of ships, and eminent men, such as Professor Rankine and Dr. Woolley, Mr. Scott Russell, and especially Mr. Froude, have presented very interesting Papers, yet unluckily these high studies have not hitherto made known the remedy so much

* Invented by Admiral Paris and his Son, Lieut. Paris, of the French Imperial Navy. Received 30th March, 1867.

desired by passengers as well as by professional men. We know the child is down the well, but we can't find a rope to draw him up.

If it be permissible to suggest a cause for this state of things, it is due, we believe, not to the want of science, but to the difficulty of measuring the causes of the motions and their extent. The first are the changes of level—so often enormous—of the waves under the continued action of the wind; the second is the rolling, which deprives the passenger of repose, and the gunner of all accuracy of aim, and by which the iron-clad ship loses much of the security which has been so dearly purchased by her heavy armour. How are we to investigate useful rules, when we know neither the height nor the form of waves, which are looked upon by some as moving mountains, while to other minds they appear as small oscillations? All is yet really unknown with reference to these waves, which we have all of us so often and so long looked at during our life at sea. This want of knowledge of the actual motion of the waves is the best excuse for that heavy rolling of our vessels, which compels us to keep all our ports shut, exposes the unprotected bottom below the armour plating, and even wounds our men, by throwing them violently against the side of the ship. It is not from wilfully bad design that ships are made to roll so much. Why then do they roll so badly at sea? Right sense compels us to confess that, from not knowing the why and the how, the remedy also remains unknown. It is impossible to escape this dilemma.

It is not astonishing, therefore, that in view of this position, some of us should have looked for the means of ascertaining at least the effect, and the cause, leaving to others more learned, the task of analysing the consequences. We must first try to rid ourselves of theories which rest on no established basis. One part of the problem has been studied, namely, the effect of the waves, that is to say, the rolling of ships; but no proposal has come to my knowledge for measuring the cause, that is to say, the waves themselves.

While at sea, we have all of us much time for reflection. I have thus thought, for many years, and especially since I saw the trials of an iron-clad in the year 1860, that it might be possible to measure the waves, so long as the weather permits the seaman to keep his ship well in hand; for there are times when he has enough to do to attend to his bare safety, without looking after experiments. But moderate weather is more frequently met with, and it is certainly possible to study the waves in the ordinary course of navigation, and, from a consideration of the less elevated waves, we may be enabled to infer the form of the exceptional ridges.

Every seaman has noticed a boat-hook floating in the sea. The weight of the iron hook keeps it upright, and the handle is so thin, that its displacement varies but little while the water rises and falls about it. The weights raised out of water one minute,

and sunk the next, are too small to overcome the inertia of the total weight of the pole during the short duration of each oscillation of the waves. In fact, the pole has not time to get in motion, but is like a top or a coin, which spin without falling, the motion changing so quickly that it has no time to fall on either side. When the rotation is abating, the oscillations begin, until the top actually falls. It appears to me, that the fact about which I am speaking is the exact reverse of the hydraulic tube used in teaching physics to shew the laws of inertia, and in which it is the outside tube which is moved more quickly than the water can follow it within the short time allowed for it. The longer the boat-hook, and the heavier its ballast at the lower end, the less will be its motion, and we may thus obtain that sort of steadiness of scale, which is needed for the comparison of all motions. This steadiness will be sufficient to enable us to observe a phenomenon so irregular in its sequence as the motion of the waves of the sea. The experiments prove that if the rod is too short, the errors of motion may be observed, and corrections made afterwards, from the measures given by the instrument itself.

After having laid aside for many years all idea of such trials, I was brought back to them by the experiments on the first iron-clad frigate. But at that time I could not come to Paris to have the instruments made; and, afterwards, being far from the ports, I had no opportunities of making the experiments. I should have thought no more of it, if my eldest son's return, after a four years' cruise in the Pacific, had not supplied me with an observer. I then applied to M. Salleron, a very able maker of physical instruments, in Paris. He executed both the instruments represented in Plates III. and IV.

The one fitted for measuring waves is formed of a pine pole of 0·15 mètres diameter below, and 0·058 mètres at the top. It is loaded with 29 kilogrammes of sheet lead rolled round the pole, so as to have but little horizontal surface. The ballast is calculated so as to keep the instrument (of which the weight must be allowed for) at 2·50 mètres above the level of smooth water. A float made of cork and oak, forming a disc, 0·30 mètres in diameter, slides freely along the pole, and is kept horizontal by a ring of iron wire made fast to the float by two rods of the same material—a contrivance looking exactly like the handing tube of a magazine. The pole being motionless, the float will be seen rising and falling, and if the staff were graduated in different colours, it would be possible to see the differences of level of the moving waves. But the quickness of motion would make a difficulty, and it would be better to make the float trace itself. My first idea, accordingly, was to have two pulleys one above the other, and an endless rope, fast to the float, passing through them. The upper pulley would then turn as the float rose and fell, and by a system of cogwheels and a rack, a tracing would have been made. But the weight of such a system would have rendered it

necessary to enlarge the pole too much, and thus make it unsteady. The successful device was due to my son, who thought that if a small india rubber tube were elongated uniformly, it might be used to make directly a proportional tracing of every linear motion, in any selected ratio of length. As india rubber possesses this property, the principle was applied by putting on the instrument an upper support sliding on a rod, to change the length of the india rubber, which is fixed at a proper length to a small carriage guided by light rods; the end is then made fast to the float, with such a tension, that there may still be room for contraction when the float is very high, and that it may still be able to stretch when the float is very low, so that neither may the machine be broken, nor the float remain suspended in the air, instead of following the surface of the sea. By this disposition, the small sliding carriage will always have a motion proportionate to that of the float; and if we add a pencil carrying ink, it will be possible to trace a diagram on a paper moved by a clock, as exhibited in the plates.

Whatever may be the dimensions of the pole, it is evidently impossible to keep it at absolute rest; but when its length is seven or eight times the height of the waves, its motion is so small that it may practically be neglected. The period of the waves has much influence, because the change of level acts as a constant force, causing the motion of the pole to resemble that of a falling body. The length mentioned above is more than is necessary for short and quick waves, but it ought to be increased for a long swell, since the effect of the change of level depends not only on the amplitude of the wave oscillation, but also on its duration. To investigate these motions, my son went to Portzic, in the Channel of Brest, with a theodolite to observe the pole, in a sea-way like that of Fig. 1, Plate V.; the maximum height of the waves being 3·15 mètres and the mean 2·35, while the oscillation was 0·35 mètres (maximum) and 0·27 (mean). There was a heavy swell, and it had blown hard during the preceding night. The motion of the pole was thus twelve per cent. on that of the waves, and the diagram had to be corrected accordingly, with reference to the position of the various points of the curve. To secure greater steadiness, the pole may be lengthened, or we may use in place of a pole a tube pierced with holes, so as to leave a free passage for the water, and the apparatus, having less floating surface, would become practically steady. It might, however, be difficult to ballast it properly so as to get the level, and to prevent its sinking. If a pole be used, it must be painted, and any shakes filled up to prevent infiltration of water. The pole actually used has sunk 0·35 mètres, shewing that about three-quarters of a kilogramme (1·62 lbs. avoirdupois) of water has soaked into it.

Stability of form must be disregarded, and the ballast must be sufficient to keep the pole upright against wind. In the experiments it was found that the pole never

heeled over more than 10°. To keep the instrument out of reach of the waves, the length of the pole out of the water should exceed half the height of the waves. As actually used, it is 2·50 mètres.

The diameter of the float is 0·30 mètres, and its thickness 0·03. It must be heavy enough to stretch the india rubber tube, and, therefore, it is made of oak and cork. The pole should be tallowed.

The paper must be carefully wrapped on the roller. It works well when it has been rolled and unrolled once before, and it should be a little narrower than the space between the flanges of the roller. Without this precaution the machine may stop. Sometimes the wind unrolls the paper, which is then liable to be torn off; but this may be avoided by putting the whole into a box. The first roller of the supply must not be too tight, or it will check the speed. The present instrument will not hold more than 12 mètres of paper. It has been used in the drizzling rain so frequent at Brest with a south-west wind, and the paper then split; but this also might be obviated by a case. The ink-glass works very well, especially when well filled. The cotton at its neck should be untwisted. Blue ink is the best: it dries soonest. The position of the ink-glass is difficult to settle exactly; if it be too near the paper the diagram is too wide, and the supply of ink will not hold out to the end: if too far off the diagram will be at times interrupted. The slider must be well oiled, and care must be taken, in letting go the instrument, that the india rubber tube shall not be twisted about the pole. This never happens while the float is in motion.

The two india rubber tubes must be cut from one piece, to secure uniform elasticity. They should be renewed occasionally, and carefully fastened to the carriages:—they should be of such length as to be slightly stretched when the float is at its highest. The india rubber used has been from 6 to 7 millimètres in diameter.

The clockwork is regular enough in its movement; its speed can be varied, by means of the fly, from 8 to 13 centimètres per second: the slower movement is the better. With care, the machinery works very well, but its state should be ascertained by trying the speed of the paper. The tracer should be so placed that the pencil's point shall be directed to the middle line of the paper when in smooth water; if the sea to be observed be high, the tracer should be adjusted beforehand.

When a diagram is to be traced, the apparatus is prepared as already described, the ink-glass and pencil being adjusted (when possible) at the last moment. The way of the ship, or boat, is then stopped; and the pole, having a log line made fast to its middle for the purpose of hauling it on board at the end of the operation, is then slowly immersed, two men keeping the head of the pole: the float is then passed over the pole,

the instrument fixed on the top by means of the spring hooks, the india rubber got clear, the clockwork set in motion by releasing its stop, and the whole is let go when the pole is at mid-immersion. Then the float may be seen to rise and fall with the water as if a part of it. When the paper has been all used, the pole is hauled slowly alongside and brought on board in a few seconds. By means of the spring hooks, the instrument is easily fixed on the pole's head or removed from it.

When the height of the waves is less than a mètre, it is best to work from a small boat; but, with a heavy sea, the oars are troublesome and seas may be shipped, or the instrument wetted. With the small schooner *Esmeralda*, of 18 mètres length, 6 mètres beam, and 40 tons burthen, my son measured waves of 3 mètres, which are those of a heavy sea. This was in the goulet of Brest, where the eddy current and the vicinity of the land produce much irregularity, and the apparatus worked well; the little vessel could not well encounter a higher sea. What would be better is a small screw steam ship with the bowsprit taken in and a square sail fitted on the mizen mast; the log line attached to the pole could thus be kept clear, and by the screw working ahead at a suitable speed, the ship would steer without making headway. I have often adopted this method when taking another ship in tow, or when waiting for a boat sent on shore.

It will be observed, that this instrument does not trace the mean level of the sea; it must therefore be deduced from the wave diagram with the mean ordinates. It would be better, however, to have a line shewing the mean level traced by the instrument itself; and this can easily be accomplished by means of another ink-glass and pencil being adjusted to a vertical rod at the side of the roller, so as to trace a straight line indicating the mean level as shown by the wave tracer when the float is on smooth water. This addition would be useful, in so far as the mean level thus shown would be more exact than that derived by calculation from the wave diagram.

According as the paper moves more or less quickly, the wave traeing will, of course, be more or less extended. Therefore, to complete the experiments, my son several times measured the length of the waves by a float towed at the end of a log line, taking the bearings according to time, in seconds, in relation to the length of the *Esmeralda* and her speed. He found 7 to 8 mètres per second, that is to say $13\frac{1}{2}$ to $15\frac{1}{2}$ knots an hour. By means of the speeds thus found he corrected the diagrams and traced the true forms of the waves, as shown in Figs. 5, 6 and 7, Plate V. He proeeeded as follows :—he reduced the original diagram to the scale of 0·02 mètres, or 2 centimètres per mètre, and marked on the diagram divisions corresponding to $\frac{1}{4}$th of a second (this was in accordance with the speed of the paper). The speed of the waves being 8 mètres per second, he put divisions of 4 centimètres each, representing, at the scale of $\frac{1}{50}$th, the length of the waves during $\frac{1}{4}$th of a second. He then drew a line on which he marked the heights shown by the

diagram, that is, the heights shown by the original tracing reduced to the scale of $\frac{1}{50}$th. In looking at the diagrams, the direction of the waves must be viewed as from the left to the right hand. An inspection of the diagrams will shew that, however variable may be the forms of the waves, they have many features in common. It must be observed, also, that the speeds of all the waves are equal. We very seldom see waves overrunning each other, as would be the case if their speeds differed.

2.—*The Roll-Tracer.*

The second subject to which I have invited attention, is the measuring of the *extent* of the rolling of ships. The pendulum has been used for this purpose under the name of "Oscillometer," but it can only give the angles of inclination so long as it remains motionless itself: the more it moves, the less exact, obviously, must be its indications. I obtained some idea of this by suspending leaden balls, by means of similar ropes, at different heights (from the bottom of the ship up to the deck) from one of the ship's stanchions. I was astonished to find how low the point of least motion (which is probably the centre of gyration) was situated. The incorrectness of this process induced me to try another, when our iron-clad frigates were tried at sea. The plan I adopted was to place a series of thin wooden sticks over the hammock nettings on each side of the ship, amidships, and to fix a plank athwartships in such a position and at such a height that, by looking along its upper edge, the horizon would meet the observer's eye at the extremity of each roll. The distance of the observer's eye from the sticks, and the intervals between the sticks being known, it was easy to calculate the degrees of the oscillations; and, in order to facilitate accuracy of observation, the sticks were painted of various colours—green expressing 10°, yellow 15°, and so on. One person at each end of the plank observed the opposite horizon line (the view of which was occasionally interrupted by the crests of the waves), and a third person was required to note the seconds of time of each oscillation. During night, of course, no observations could be made.

Many years ago the idea occurred to me that a large spinning top might be used for the purpose of sustaining a pencil in a vertical position, so as to make a tracing upon paper drawn across it by the motions of the ship; but the circumstances before alluded to prevented my following out the idea. This bears some analogy to the arrangement described by Mr. Piazzi Smyth in Vol. IV. of your *Transactions*, which requires two

observers to attend to the instrument, and a third to note the seconds of time of the oscillations. Mr. Smyth's arrangement has the advantage of giving, separately, the pitching (if it be of any interest) as well as the *rolling*. In 1866, M. Normand, son of the celebrated shipbuilder at Le Hâvre, produced before a Meeting of your Institution his "New Ship Clinometer," a description and drawings of which are given in Vol. VII. of your *Transactions*. However valuable these instruments may be, they have the defect of not themselves recording the effects which they indicate; and now, when curve tracers have been found so useful, especially in analysing the action of steam by means of the indicator, it seems preferable that oscillometers should be made self-registering,—they should present us with diagrams, showing the extent and periods of the oscillations, as much to be depended upon, at distant times and places, as are those representations, obtained by means of photography, of what we may have seen in China or Japan twenty years ago.

With this view, it occurred to me to use a top of such rotatory power as to overcome the counteracting friction of a pencil tracing upon paper. My first idea (wishing to avoid the inconveniences of a universal joint) was to suspend the top by a gut string, the flexibility of which would permit the axis of the top to remain vertical, while the rotatory motion, beginning slowly, would increase in rapidity. Care would require to be taken to avoid breaking the string when stopping the top. Cog wheels would have been disposed so as to give motion to the top by hand, or from the shaft of the steam engine, if a continuous observation were required, and the paper could have been moved by the same means. With such an arrangement, unless regulated clockwork were used, the speed of motion of the paper would require to be noted. The pencil, in this case, would be below the top, and the paper would be passed along between two arched wires, so as to give it a cylindrical form.

M. Salleron, the maker of the wave-tracer, shewed me various gyroscopes, turning on a pivot like tops, and he constructed the roll-tracer now before you. (*See* Plate IV.)

The top is a perfectly equilibrated horizontal metallic ring attached above, by three or four oblique radii, to a vertical rod, the lower end of which is of pointed steel, and is pivoted on an agate bearing. To set the top in motion, a pack-thread is wound round the rod and then withdrawn with gradually increasing force, the rod being kept steady between the notched branches of a pair of scissors, during both operations, and until the rod attains, by means of the rotation of the top, a steady vertical position, when it is released by opening the scissors. The top will revolve without oscillating for 30 to 35 minutes, so that long observations can be made.

The whole apparatus is arranged on an oblong board, at one extremity of which is

a roller bearing the paper. The paper is drawn at a proper speed towards the other end of the board by means of clockwork, and in order that the pencil, borne upon the top of the rod of the top, may at all times have a uniform pressure, a cylindrical form is given to the paper by means of two pairs of arches (one before and the other behind the top), each having a radius equal to the distance between the bearing of the top and the point of the pencil. To prevent such a degree of friction as would retard the motion of the clockwork being caused by the passage of the paper through these arches, their adjacent edges are lined with numerous small rollers which yield to the motion of the paper. The paper is guided in a proper direction towards the arch by two copper plates, borne upon pillars, one on each side of the board, which are found sufficient for the purpose even in a fresh breeze and in a boat. The motion of the paper is very regular, and its speed can easily be regulated with the aid of a watch marking seconds, and by making a mark at every unit of time upon the paper as it passes.

The right working of the instrument depends mainly upon the manner in which the top spins. With seven or eight revolutions per second it remains steady, and quite a strong pressure is required to divert it from the right line. If the axis of the top be not vertical at starting, and the paper be steady and the plank motionless, the pencil will trace a gradually diminishing cone, the breadth of which may be seen on the paper. Consequently, if the observation be commenced before the axis is vertical, it is not proper to measure the diagrams from the edges of the paper to know the angles, but their sum for both rolls will be got by the comparisons of the opposite extremes of the diagrams.

If the top be tried at various speeds, it will be seen that the oscillations last longest when the rotation is quickest. The speed being *nil*, it falls into the case of the compound pendulum. The angle which the axis makes with the vertical at starting the top rapidly lessens, and, after the speed has sunk to ten revolutions per second, the axis is practically vertical. The following figures shew the periods of the oscillations of the top at various speeds of revolution:—

Number of Revolutions of Top per Second.	Corresponding time of Oscillatory Revolution.
23	54 seconds
21	51 „
19	48 „
17	45 „
15	41 „
13	37 „
11	32 „
8	20 „
6	11·5 „
5	9·8 „

These figures are the mean of four observations which closely agreed. With twelve revolutions per second, the top's motion is rapid, and it is perfectly steady. Once, the top having started with twenty-three revolutions per second, its speed was found to be ten revolutions per second after the lapse of nine minutes.

If the periods of the rolling be short, as with a boat or small ship, this oscillatory motion of the top is immaterial; but in the case of a large ship, where the period of the rolling may be ten seconds, the form of the diagram would not be true, and it would be better to wait four minutes after starting the top, so as to let the axis become vertical and steady, and then to give some ink to the pencil before setting the paper in motion. On board a large ship, however, it is very easy to set the top in motion with its axis vertical, and then there would be no occasion to wait more than one minute.

The pencil (a camel hair pencil, such as is used for water colours) must not be too sharp in the point; it must be well fastened to the upper end of the rod of the top, and, as it points upwards, it must be well filled with ink. It is easy, by means of another pencil, to renew the supply of ink, and thus a diagram may be traced all along the 12 mètres of paper, which may be made to pass over the pencil in ten minutes. If the pencil do not point exactly in the line of the axis of rotation, the diagram will be formed of a series of little curls, as shown in Fig. 14 (Plate V.), which is a full-sized diagram. One side of these curls forms a continuous line, so the eccentricity of the pencil's point produces no error. And from their number, together with the speed of the paper, the number of revolutions of the gig per second may be ascertained.

The mean vertical position of the ship may be indicated either by a line drawn along the centre of the paper, so as to shew the rolling to starboard or port, or (as will be found better) by a line traced by a pencil fixed in the proper position, which can easily be arranged.

There is no difficulty in setting the top in motion:—in stopping it, however, care must be taken. If seized with the nippers or by the fingers, it will jump out of the bearing and be in danger of bending its rod. The best way is to press a finger gently on each side of the rim, on its lower surface, which will produce sufficient friction to stop it quickly and without shock. The agate bearing must be well oiled—want of oil is indicated by a peculiar noise.

The paper must be carefully wound upon the roller, so that it may unroll evenly, otherwise it will stop the clock motion, or be torn. The motion of the clockwork is very regular:—at first, its speed was 0·077 mètres per second, which was too fast. For the motion of boats 0·035 mètres, and for large ships 0·012 mètres per second are suitable speeds. If it be wished to compare the rolling of different ships, a uniform speed of the paper should be adopted.

Subjoined is a tabulated summary of the results of some experiments made by my son at Brest. Those on the motions of a floating body were made with a ship's boat of 7·50 mètres length and 2·20 mètres beam, the lines of which were measured, and the centre of capacity, displacement, &c., carefully calculated for each case. For the purpose of comparing the rolling with its causes—diagrams of the waves and of the rollings were traced at the same time. The weather is so changeable, and the waves are so much disturbed by tides, that such observations cannot be made in these seas with so much exactness as in the Mediterranean; these results are only given, therefore, as specimens of what could be done with very limited means. In the case of high seas, the experiments were made on board of a small schooner which Admiral Dupouy, Préfet Maritime, had the kindness to lend, and which answered the purpose well.

After describing these instruments, and giving the results of some experiments made with them, the question naturally arises, "Of what use are they?" The answer is: "Of no use at all if we are content with such knowledge as we already possess regarding the motions of ships; but if we desire to gain more light upon a subject of such vital importance to the efficiency of our ships, we may rely upon it, that the means of measuring the causes of these motions, and of comparing cause with effect, will be found of as much practical value to the naval architect as the indicator of the steam-engine has been to the engineer."

Certainly, diagrams of the rolling of ships cannot compare with the information given by the indicator, so far as regards the facility of deriving useful results from them; the mechanical action to which the former refer being much more complicated than that of the pressure of steam upon the piston; but they supply a want in an important field of observation which has been until now too much neglected, because of that very want of the means of obtaining elementary information.

The diagrams on Plate V., although reduced to one-fifth of the size of the original tracings, shew distinctly the variations due to the difference of height and character of the waves which produced them. The periods of the rollings of a boat vary according as the ballast is in the bottom of the boat or on the sides, and according as the masts are kept standing or unshipped; and this is found to be the case whether the rolling be produced by wave motion or by artificial means in smooth water, such as by inclining the boat until the gunwale is on a level with the water, by means of a rope passed under her keel, and then letting her go (called on the diagrams, "rolling in calm water.") Even with the violent motion produced by the use of a rope as described, the top remained perfectly steady, as was proved by the tracing produced when the rolling of

the boat had ceased. It must be observed that a boat is not well fitted for such experiments, because its stability of form has too much influence, as shown by the position of the metacentre given in the Table.

As to the practical value of these instruments, I believe shipbuilders would find great advantage from the study of diagrams of the behaviour at sea of the ships constructed by them; the forms of the ships, and the dispositions of the weights being known.

Finally, if seamen are ever fortunate enough to see good experiments made by learned men on rolling, I believe it will be by means of instruments like those now before you. And if such experiments be not so attractive in themselves or so flattering in their results as those short but expensive trials of speed, they will not be less useful. The weights within the ship may be moved from one position to another, but such changes only apply to what we may term the passive parts, because weights have no action except when put in motion. The form of the ship's skin is what gives a hold to the waves so as to *cause* motion, the nature and extent of the motion being influenced according to the inertia and the position of the weights. What these mutual influences may be—what the influence of proportion of length, breadth, and depth of ships—what the isochronism of a pendulum, unaffected by the vertical motion of waves, may be as compared with the isochronism of a pendulum subjected to that disturbing influence, whether we must adopt tumbling home or flat and upright sides for our ships, or the cylindrical form shown in Mr. Winan's (cigar-shaped) yacht, in order to prevent excessive rolling—whether rafts such as the Monitors, constantly under water, or long and fine ships, or ships more or less flat-bottomed be the least liable to roll heavily—where is the man who can yet say, "I will build you a ship which shall not roll much?" If there be such a man, what are the data on which he bases his system? And why have shipbuilders spent so much time and money without attaining what is so desirable, even to the present time? To these questions we can only answer, "Nothing until now, except by individual guesses, and without recorded measures."

There is one experiment which I regret my son has not made, *viz.*, the measuring of the rolling of a cask in various conditions, *e.g.*, immersed to one-third or to one-half the radius, to the centre and over the centre, with sheet lead outside, or with central ballast. Such experiments would not of themselves solve the question of rolling, but what fruits might they not bear if handled by Mr. Froude? Instead of continuing to build most expensive ships, and looking to their performance or behaviour for information as to how others should be built, is it not possible to build an experimental ship of wood secured to angle-iron framing by means of screws, so that, after experimenting

with varied dispositions of weights, the planks might be unscrewed, the angle-irons heated and altered so as to give a new form to the ship, and the same planks (with little trouble or expense) used in the construction of a ship of the new form? With a ship 30 mètres or 40 mètres long, changed in form, in the course of one or two months, and towed (to avoid the fitting and unfitting of a steam propeller), it is probable that principles might be arrived at which would enable us to lessen that tendency towards inordinate rolling which characterises our modern ships of war. Such experiments could be made as methodically as those on the screw propeller of Messrs. Bourgois and Mall. Unfortunately, Governments only can bear the expense of such experiments, and the dreadful realities of a war are required to convince them (when too late) that, in order that the advantages of heavy armour-plating, costly in itself, and so much more costly when it leads to shipwreck, may not be lost, the power of aiming and manœuvring the guns must be secured. The subject is worth serious consideration, and such experiments would certainly be as useful as those made for the purpose of solving the question between armour plates and ordnance, or those for showing the greatest speed at which a ship can be driven for a period of four or five minutes.

Naval officers cannot long continue such experiments. After using these instruments for some months, my son had to confine his experiments to those made in a boat of the ship on board of which he was an officer. Corrections had to be made of the tracings of high seas by causing the pole to oscillate vertically in smooth water, when the mean period of the oscillations was found to be ten seconds, the upward movement of the pole being a little shorter than the downward movement, owing to the resistance of the india-rubber. The diagrams traced in this manner, in smooth water, proved that no corrections were required when the waves lasted no longer than two seconds; and, when they lasted longer than that time, it was found that these observations, when corrected by calculation, agreed in their results with those made from the shore.

From more than twenty observations of each kind, made in the Bay of Brest, or along the north coast of Bretagne, the most remarkable diagrams have been selected. They are given (reduced to the scale of $\frac{1}{5}$th of the original tracing) in Plate V. Fig. 2 represents a very rough sea, observed with a strong ebb current against a fresh wind. The same waves are shown in Fig. 7 on the scale of $\frac{1}{400}$th of the height of the waves. The small schooner *Esmeralda*, as well as the boat, and the pole which were used, are shown on the proper scale. Fig. 4 represents a tracing taken of very small waves inside the Bay and near the land, where the tidal currents make the sea very irregular; in the offing, a sea of such a character is not found. On the diagrams, a straight horizontal line may often be remarked on the top of the wave; it is produced by the float being covered by the

foam of a breaking wave. When this flat-line is extensive, it shews that breaking waves progress less quickly than a long swell.

The diagrams of the rollings show both their extent and their periods. Knowing the radius of the spindle of the top, we are enabled to calculate the degrees of the oscillations; and their periods are ascertained from knowledge of the speed of the paper, which may be verified during the course of the experiment. The measure of the radius of a given curvature on the diagram and the speed at which the paper travels, together shew the working of the vessel at that particular time, and thus it is possible to ascertain whether one ship works more heavily than another. Observations have several times been made simultaneously with both instruments, and this is the best way of obtaining diagrams to be presented for the consideration of learned and scientific men. The angular velocity of the ship's roll at its highest point, which it is so important to keep small, for the sake of aiming the guns, may easily be measured by the tangents of the curves traced out.

Experiments were made on the influence of the position of weights in a boat of 7·50 mètres, the various conditions of which are shown in the Table appended. I will here, therefore, merely give general results. There were 525 kilogrammes of ballast, consisting of pigs of 25 kilogrammes each; these were variously placed, on the keelson amidships, and all along the middle on the thwarts; after that, on the sides close to the plank; and finally, they were hung on the outsides like armour plates. There were generally three men in the boat, two with the instrument behind the mainmast, and a third forward, to haul on a rope, when required. When the masts were up, or sails, oars, &c., were on board, it has been specially mentioned, but generally there was nothing on board but a pair of oars, the instrument, and two men.

Figs. 8 and 9 shew the oscillations in smooth water, produced by a rope being fastened to a thwart, passed under the keel and up the other side, and hauled from a yard until the gunwale was close to the water's edge, and then let go suddenly. Nothing was in the boat except three men, the ballast and the instrument. In the case of Fig. 8, the ballast was laid along on the thwarts; in that of Fig. 9, it was below, on the keelson. There is a very perceptible difference between the rolling indicated by these two diagrams,—that shown in Fig. 9 being quicker and heavier than in Fig. 8. It is to be remarked, that oscillations of greater degree have shorter periods than those less in degree; this, in such a boat, is because the metacentre is greatly raised by the inclination of the boat and consequently the *return* is quick:—the effect is similar to that produced on a pendulum by pushing it with the hand at each extremity of its oscillation. The irregularity observable in the beginning of Fig. 8 was produced by the shock of the boat striking the ship's side; and, besides that, the equality of the rolling to starboard

and port was disturbed by the vicinity of the large ship. It is better to make such experiments in open water.

The other trials were made in the middle of the Road of Brest. A rope from the boat was made fast to a buoy, to avoid having more than the observers and one man on board. When the rope was let go, the boat rode beam on to the sea and rolled freely, and, after the diagrams had been traced, she was hauled close to the buoy ready for a new observation. The elements of the Table were calculated from an exact plan of the boat, and its centre of gravity was calculated by the weighting her as she hung from her tackles.

The following are the general results of these small experiments:—

When the moment of inertia is great, the rolls are more extensive and the *returns* are smooth; in which case those broken parts are seldom seen in the middle of the diagram which are frequently seen in the opposite case, as shown in Figs. 11 and 12. The diagrams and the rollings of which they are the expression, are more regular when the ballast is far from the centre, as shown in Fig. 10. It should be mentioned however, that once when, with a low centre of gravity and great momentum of inertia, the rolling was large and violent (quick), the masts were on board and in place. Also that with the ballast suspended outside, the roll was for a time short and violent (quick), as shown in Fig. 10, a portion of which shews the rolling to have been very regular and smooth. When there was little difference between the periods of the natural rolls and the time of passage of the waves, the ballast being winged, the rolls were large considering what the sea was at the time.

When the moment of inertia is small, the diagram takes somewhat the form of a series of right lines (like a saw) with the angles a little rounded; but, when it is great, the diagram is more undulating.

The angular velocity appears to have greater maxima (the extent, or degree, of rolling being equal) when the ballast is placed low.

The rolling is not equally quick on both sides; very often to windward the diagram is sharper, but it is not regular, and it appears from a series that the angular motion is quickest as the weather side rises.

The time of rolling agrees, nearly, with that of the natural oscillations—it is always shorter with a head wind than with the wind abeam.

Generally, the mean time between the passage of waves has been a little longer than that of the oscillations; and, this was usually intermediate between the time of natural rolling and that of the passage of the waves.

An inspection of the diagrams will make it evident that the influence of the waves was greater, and the boat followed their motions more easily, when the moment of inertia was small.

The motions are always less extensive, often one half less, and the *returns* are less violent, with the wind ahead, than when it is abeam.

The maxima and minima give very little notion of the irregularities of the motion. From the examination of the numbers used in obtaining the means, it appears that the time is more regular with the ballast in the bottom of the boat. With the ballast on the thwarts, when the moment of inertia and the stability were both small, the time, 2″, was almost exactly that of the waves 2″·18, although the natural period of oscillation was different, namely 1″·18.

Under sail, whether the boat be close hauled to the wind or going before it, the rolling is slow.

It is evident that those results are not absolutely reliable; and in a single diagram, taking it altogether, anomalies are to be seen which appear like inconsistencies. It is because in the Road of Brest the tide produces much irregularity in the waves, and in a small boat the observers themselves influence its motions. Besides that, it must be remarked that a boat is so flat that its stability of form has a much greater influence than in a sea-going ship, and, consequently, the variations in the position of the weights exert less influence. Therefore the results deduced from these diagrams are not applicable to ships, and the diagrams as well as the description of the instruments are given only to shew what we could do with our small opportunities, and to prove that from such observations we may hope to derive data of an exactness impossible of attainment without actual measurement—data which will be of use to learned and scientific men in their endeavours to throw light upon the subject, hitherto involved in obscurity, of the motions of ships at sea. This is the only reason which induced me to publish an account of these little experiments. I do so specially in the hope that some learned society, such as the Institution of Naval Architects, may take the question in hand, and endow seamen and the world with the beneficial results which may be expected from their investigations.

	State of We
1	Cloudy and s breeze unst
2	S.W.breeze; sea; rain d
3	Light breeze steady and
4	A strong squ
5	,,
6	Fine weathe breeze.
7	,,
8	Squally weat breeze unst
9	,,
10	,,
11	,,
12	The breeze is S.W.
13	,,
14	The breeze b blows from
15	,,
16	,,

RESULTS OF TRACINGS OF WAVES AND ROLLINGS.

	State of Weather and Wind.	Weights placed on Board, and their Stowage.	Currents.	Direction of the Boat compared with that of Wind.	Displacement.	Mean Draught.	Height of centre of gravity above the lower line of rabbet.	Height of centre of displacement above the lower line of rabbet.	Distance from metacentre to centre of displacement.	Distance from metacentre to centre of gravity.	Moment of Inertia.	Time of Oscillations on Smooth Water.	Extent of Rolling.			Time of Rolling.			Extent of Waves.			Time between the Passage of Successive Waves.		
													Mean.	Maxima.	Minima.	Mean.	Maxima.	Minima.	Mean.	Maxima.	Minima.	Mean.	Maxima.	Minima.
					Cubic decr.	Mètre.	Mètre.	Mètre.	Mètre.	Mètre.	Kilogram-mètres.	Seconds.	Degrees.			Seconds.			Mètres.			Seconds.		
1	Cloudy and squally weather. Fine breeze unsteady.	Five men; masts up; boat's armament, 525 kilogrammes of ballast in pig placed in the middle and bottom.	Flood ¾ knot.	Across.	1880	0.46	0.42	0.21	1.49	1.28	1811	1.73	13.2	20.9	7.8	1.89	2.80	1.50	0.42	0.86	0.15	2.05	4.5	1.1
2	S.W. breeze; rippling and unsteady sea; rain during the squalls.	Same arrangements.	Flood ¾ knot.	Ahead.	1880	,,	,,	,,	,,	,,	,,	2.00	6.35	11.3	2.7	1.82	2.12	1.00	,,	,,	,,	,,	,,	,,
3	Light breeze, calming; sea unsteady and ripply, abating.	Same arrangements. Iron pigs placed on thwarts along sides.	In the same direction as wind.	Across.	1880	0.46	0.54	0.21	1.49	1.16	2185	2.00	14.12	26.8	6.82	1.95	3.00	1.4	0.16	0.28	0.05	2.27	3.7	1.3
4	A strong squall of wind.	Same arrangements of all.	,, ,,	Across.	,,	,,	,,	,,	,,	,,	,,	,,	14.25	26.8	1.80	1.88	2.7	1.1	,,	,,	,,	,,	,,	,,
5	,, ,,	,, ,,	,, ,,	Ahead.	,,	,,	,,	,,	,,	,,	,,	,,	7.35	14.1	1.40	1.72	2.5	1.1	,,	,,	,,	,,	,,	,,
6	Fine weather; N.W. very light breeze.	There were in the boat, 3 men, 2 oars, 1 boathook, and 525 kilogrammes of pig iron ballast. Ballast on the thwarts alongside.	Low flood.	Across.	1770	0.43	0.50	0.19	1.58	1.34	1699	1.73	2.37	5.0	0.9	1.76	3.05	0.79	0.09	0.22	0.02	1.82	3.91	0.70
7	,, ,,	In the middle and on keelson.		Across.	1770	0.43	0.34	0.19	1.58	1.43	1302	1.47	1.84	5.40	0.9	1.15	1.9	0.7	,,	,,	,,	,,	,,	,,
8	Squally weather; fresh W.N.W. breeze unsteady.	On the thwarts alongside.	Flood running 1 knot and a half quite in the same direction as wind.	Across.	1770	0.43	0.50	0.19	1.58	1.34	1699	1.73	7.84	20.4	2.3	1.68	2.7	0.8	0.18	0.30	0.04	2.18	3.57	1.07
9	,, ,,	On the thwarts in the middle.		Across.	1770	0.43	0.50	0.19	1.58	1.34	1269	1.56				8.15	21.3	1.8	2.0	3.3	1.4	,,	,,	,,
10	,, ,,	,, ,,	,, ,,	Ahead.	,,	,,	,,	,,	,,	,,	,,	,,	6 72	12.27	9.7	1.59	2.6	0.90	,,	,,	,,	,,	,,	,,
11	,, ,,	All ballast suspended outside.	Same direction.	Across.	1770	0.43	0.50	0.19	1.58	1.34	1780	1.74	5.32	10.00	0.90	1.82	2.6	1.10	0.17	0.36	0.03	1.64	3.20	0.6
12	The breeze is less, and passes to S.W.	,, ,,	,, ,,	Ahead.	,,	,,	,,	,,	,,	,,	,,	,,	3.48	9.1	1.80	1.34	2.4	0.80	,,	,,	,,	,,	,,	,,
13	,, ,,	In the bottom and the middle of the boat.	,, ,,	Across.	1770	0.43	0.34	0.19	1.58	1.13	1302	1.48	6.50	17.1	0.9	1.73	2.30	0.80	,,	,,	,,	,,	,,	,,
14	The breeze becomes fresher, and blows from S.W.	,, ,,	The current less strong.	Ahead.	,,	,,	,,	,,	,,	,,	,,	,,	5.65	14.5	1.37	1.45	2.30	0.70	,,	,,	,,	,,	,,	,,
15	,, ,,	5 men on the thwarts, 2 in the stern, masts and sails up.		Close to wind on larboard tack.	2010	0.47	0.45	0.22	1.49	1.36	2391	1.95	2.40	4.55	0.90	2.40	4.5	1.2	0.13	0.37	0.03	1.59	1.58	0.73
16	,, ,,	,, ,,		Wind dead aft.	,,	,,	,,	,,	,,	,,	,,	,,				5.76	10.0	0.90	2.26	3.60	0.9	,,	,,	,,

Length of the boat, 7m. 10; beam, 2m. 20; depth, 0m. 90.

Descriptive Particulars of Plates III. and IV.

1.—*The Wave-Tracer*—(*Plate III.*)

A.—Box containing the clock motion.

B.—Fly to regulate the speed by the obliquity of wings.

C.—Stop of the fly.

D.—Cylinder receiving the motion directly from the clock.

E.—Cylinder serving to keep the store of paper.

F.—Spring pressing lightly on the base of the cylinder, to prevent it from unrolling too freely. A crank is used to roll the paper in at first.

G.—Cylinder on which the paper is rolled after the diagram has been traced; this cylinder receives its motion from the cylinder D by means of two pulleys of different diameter and pitch.

I.—Small wooden cylinders used to bring the paper close to cylinder D.

K.—Rod on which slides the ring L, used to fix the upper part of india-rubber tube, T T.

M.—Guides of the inkstand M′, which by its four branches slides freely between the guides.

N.—Inkstand resembling a teapot, with a neck, in which is an untwisted cotton thread, which marks the paper. The blue ink answered better than others.

P.—Screw, serving to regulate the distance from the inkstand to the paper.

Q.—Socket to place the apparatus on the top of the pole S.

R.—Spring hook to keep the apparatus on the summit of the pole.

T T.—India-rubber tubes fixed to the ring L, made fast after to the carriage of the inkstand M′, and at end to float V. In consequence of its elasticity, the india-rubber transmits the vertical motions of the float to the inkstand in the proportion of the length of L M′ to that of M′ V. If L M′ is one-tenth of M′ V, the diagram of the height of waves will be a decimètre to a mètre; if it is as 1 to 20, it will be 5 centimètres to a mètre. The proportions are varied according to the height of the ring L on the rod K.

2.—*The Roll-Tracer*—(*Plate IV.*)

A.—Top.

B.—Steel axis round which is rolled the pack-thread used to spin the top.

C.—Pencil fixed at the top of the steel axis.

D D.—Arches fitted with small rollers, to give a cylindrical form to the sheet of paper, which form enables the pencil to trace whatever may be its angle. The upper arch can be taken up to introduce the sheet of paper and afterwards fixed in its proper place.

E.—A kind of shears, having a notch in each leg, to catch the rod of the top while it is being set spinning with a pack-thread; when this is done the legs are opened and the top is free to keep a vertical position.

G.—Plates used as side guides of the papers.

H.—Clock-motion to move the sheet of paper.

I.—Fly regulator for the speed of paper.

K.—Stop of the fly regulator.

L L.—Cog wheels for moving the paper.

M.—Cylinder moving the paper.

N.—Cylinder on which the paper is rolled after it has passed over the moving cylinder M, by means of the pulleys O O, and a thread.

P.—Cylinder used to bring the paper close to M.

Q.—Cylinder serving as a store of paper. This one must be shorter by one millimètre at each end than the other cylinders. It must be carefully rolled with the hand-crank R.

DISCUSSION.

The CHAIRMAN: (Mr. E. J. Reed) I think we should fail in our duty if we neglected to convey to Admiral Paris our obligation for his kindness to us in sending us these instruments and exhibiting them here. The gyroscopic instrument I believe to be the only one which can perfectly record the oscillations of a ship at sea; and, however that may be, Admiral Paris has, no doubt, been at great pains to work these instruments out, and he has been kind enough to send them here for our information and inspection at a time when he would have preferred to have had them in his own city in order to have placed them in the Paris Exhibition. Admiral Paris, as many of you know, is the hydrographer to the French Admiralty, and he deeply studies all questions relating to the motions of ships. I do not know whether or not it will be necessary to move a resolution, but if you will indicate your approbation I shall be very glad.

Mr. MERRIFIELD: I think it will be better to have a formal resolution, and therefore I beg to move "That the thanks of this Institution be given to Admiral Paris, and his Son, for their kindness in "communicating their interesting Paper, and in taking the trouble to send over their ingenious "instruments for the information of the Institution."

Mr. LLOYD: I have great pleasure in seconding that resolution. [The resolution was carried with acclamation.]

CONCLUDING PROCEEDINGS.

Mr. MERRIFIELD then read the following list of proposed new Members:—

"Boy Jensen, Naval Architect, Dantzig; William Edward Seccombe, Inspector of Dockyard Works, London; Annanias Dekke, Shipbuilder, Bergen, Norway; Thomas Summers, Shipbuilder, Southampton; Charles Arthur Day, Shipbuilder, Southampton; Edward James Harland, Shipbuilder, Belfast; David Tod, Shipbuilder, Glasgow; Edward Ritherdon, Naval Architect to the India Board; John Reid, Shipbuilder, Port Glasgow; William Wain, Shipbuilder, Copenhagen; Carl Christian Burmeister, Shipbuilder, Copenhagen; William Pearce, Shipbuilding Manager for Messrs. Robert Napier and Sons, Glasgow; William Wray, Shipbuilder, Burton Stather, Lincolnshire; John Scott, youngest, Shipbuilder, Greenock."

Mr. SCOTT RUSSELL: I move that these Gentlemen be admitted Members of the Institution.

Mr. C. H. WIGRAM: I second that. [The resolution was unanimously adopted.]

Mr. MERRIFIELD read the list of Officers of the Institution, and their election was carried unanimously.

Mr. REED: The Meeting, I am sure will join cordially with me in passing a resolution which it is our strict duty to pass, and I am equally sure we shall do it with very great pleasure. It is—"That the "Honorary Secretary be requested to write a letter to the President, expressing the regret of this Meeting "that the President's official engagements should have prevented their having the advantage of his "occupying the chair this day; but thanking him for the great attention which, nevertheless, he has "shown to the interests of the Institution, and especially for his Opening Address, which, in the opinion "of this Meeting, is likely to be of great benefit to the Institution." I would submit, in reference to his attending under great disadvantages and to his anxiety to be here again to-day, as manifested in the note which we received from him, that on this occasion it would be a proper action on the part of the Institution if it authorised the Hon. Secretary to address a special note to the President saying how sensible the Institution is, not only of his great kindness in seeking, under all the pressing exigencies of his high office, to attend here, but also of the very handsome service rendered to the Institution by his opening speech, for I am sure it is quite impossible for that speech to appear even in the brief form in which it has been given in the daily papers, without bestowing great advantages on the Institution. I think the fact, that he was in office when he accepted the presidency, and has stood by us when he was out of office, and stands by us still when he is again in office and has so many pressing duties, deserves acknowledgment on our part. I beg to move that the thanks of the Meeting be given to the Right Hon. Baronet, our President, and that the Secretary be instructed to express our special sense of his kindness upon this occasion.

Mr. GRANTHAM: I beg to second that motion, Sir. [The motion was carried unanimously and with acclamation.]

Mr. SCOTT RUSSELL: I would also move, Sir, if you will allow me, that the thanks of this Meeting be given to Mr. Merrifield for the kind manner in which he has been good enough to take upon his shoulders the duties of Secretary. Mr. Merrifield has been of very great benefit to us. He is

a friend who served us in need, for when the circumstances of the Institution put us somewhat in difficulty in finding an efficient and scientific Secretary, he came forward and said—"I will do the duties of the "Secretary, on one condition only, and that is that you do not pay me for them." I therefore propose that we give our thanks to Mr. Merrifield for his great kindness in discharging the duties of the Honorary Secretary. At the same time, he will allow me, I am sure, to say that we are very much indebted indeed to Mr. Campbell for the assiduity with which he discharges the duties of Assistant Secretary, and for the conscientiousness with which he performs all the duties committed to his trust; and we hope he will not consider that those services are not thoroughly and entirely appreciated, although they are not, perhaps, services so palpable to a General Meeting as to those who have more occasion to know the difficulty of carrying on, as he does, the daily duties of the office. Those duties are far more arduous, and far more complicated, and demand much more time than any one can conceive who does not know how essential the Secretary's work is to the success of an Institution.

Sir EDWARD BELCHER: I beg leave to second that. [The resolution was carried unanimously.]

Mr. MERRIFIELD: Gentlemen, I beg to thank you for the compliment which you have paid me, and to add my small testimony, if I may be allowed to say so, to the great and valuable assistance which Mr. Campbell renders.

Mr. WHITE: The business is not quite done, and I rise to propose a vote of thanks to the Chairman. He is a gentleman who is thrown into a sphere where he can obtain, and does obtain, great practical knowledge of, and information upon all the subjects which have been brought before the Institution; and I have much pleasure in proposing a vote of thanks to Mr. Ritchie for having taken the chair on this occasion.

Mr. GRANTHAM: I beg to second that most cordially and to express my appreciation of his great impartiality. [The motion was adopted.]

The CHAIRMAN: The meeting was easily managed.

Mr. MERRIFIELD: Before we separate I must ask you to instruct me to communicate a resolution from you to the Council of the Society of Arts for their extreme kindness in granting us the use of this room.

Mr. SCOTT RUSSELL seconded this proposition, which was adopted unanimously.

The CHAIRMAN: That, Gentlemen, concludes our business. I think we have had during the last few days some most successful meetings.

NOMINAL INDEX.

NOMINAL INDEX.

Being an Alphabetical List of the Names of the Authors of Papers read before the Institution, and of the Speakers who took part in the Discussions which followed the Reading of the Papers.

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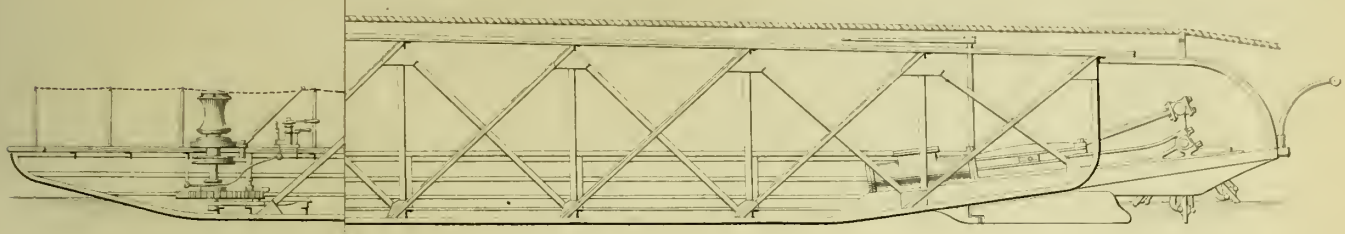
cry River.



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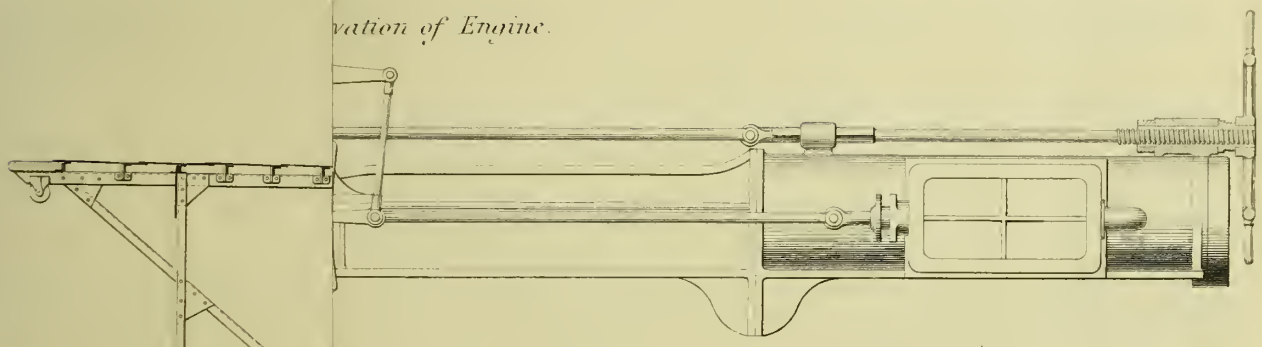

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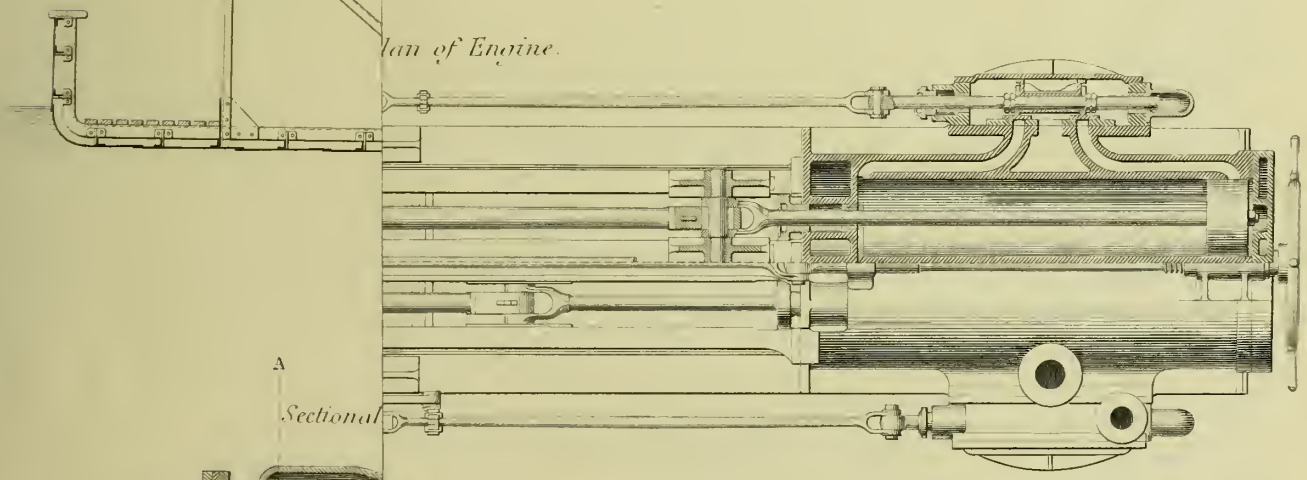
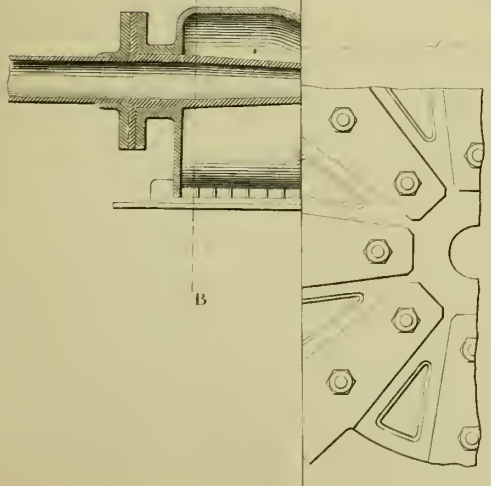
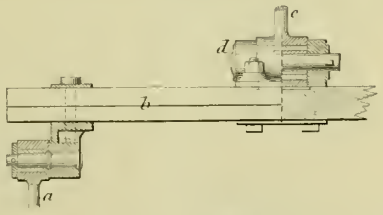


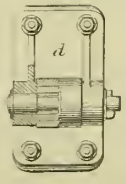
A

Sectional





Details of Paddle wheel



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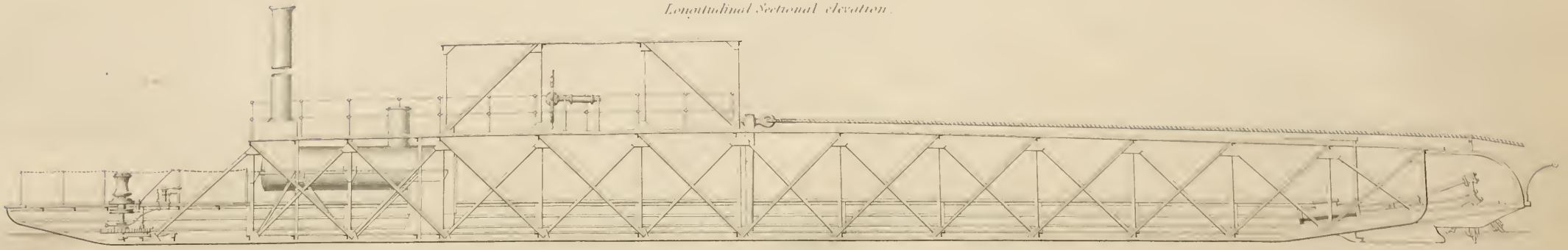
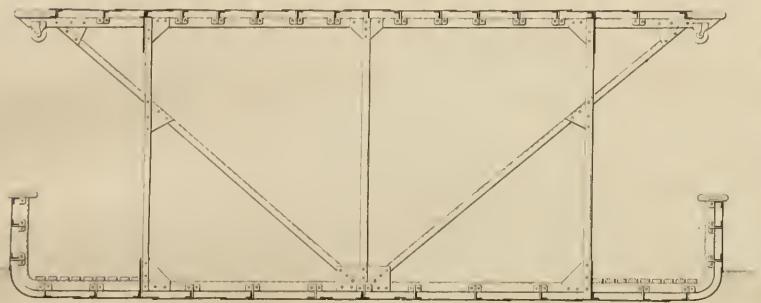
To illustrate Mr James R. Napiers Paper on Tug Steamers for the Godavery river

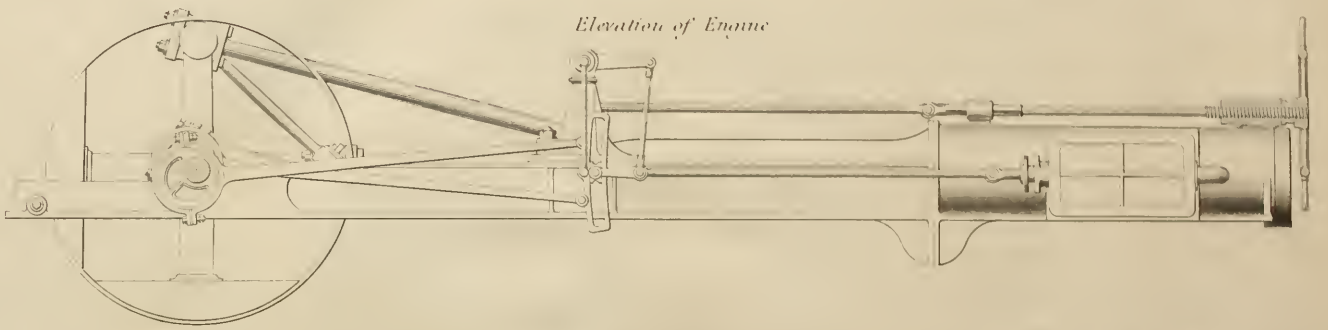
Longitudinal Sectional elevation.



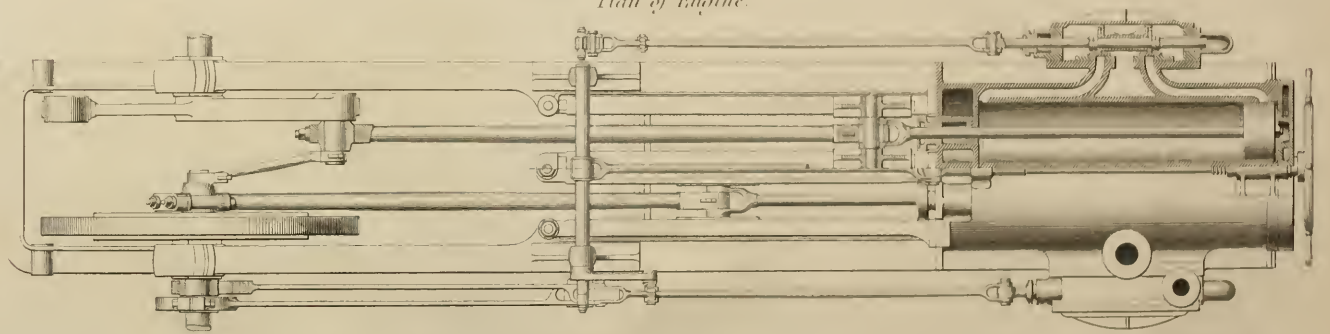
Cross Section of Boat



Elevation of Engine

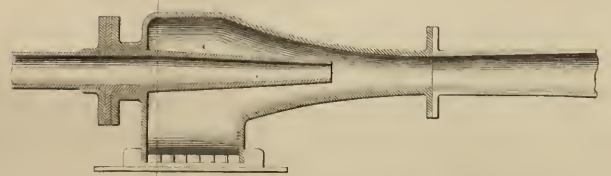


Plan of Engine.



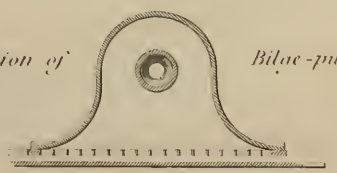
A

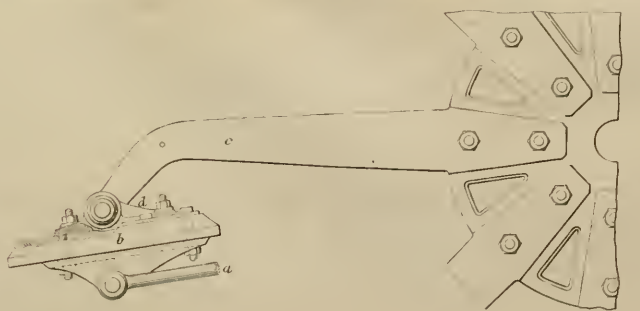
Sectional elevation of Bilge pump.



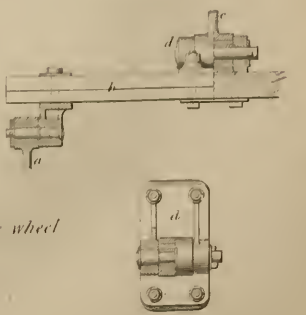
B

Section of Bilge-pump through AB.





Details of Paddle wheel



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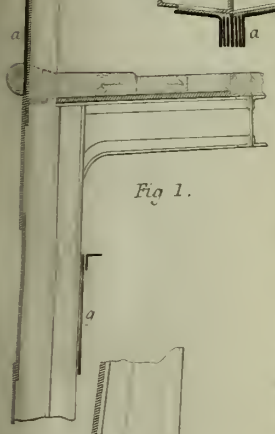
To illustrate Mr Reed's Paper on Cases of Weakness in Iron Ships.

Fig 1.



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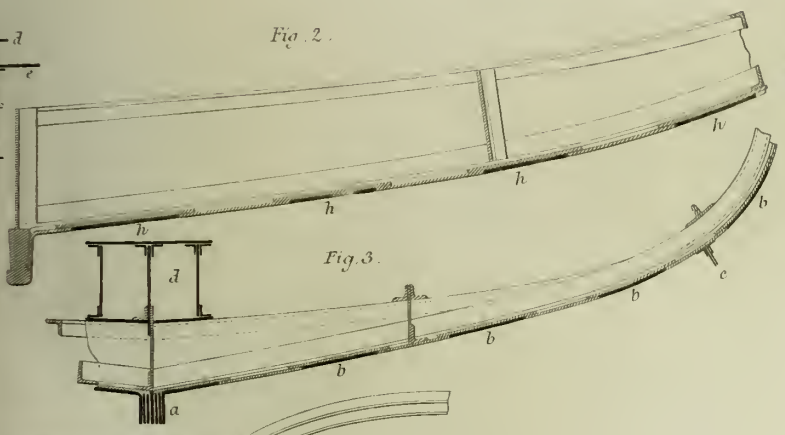
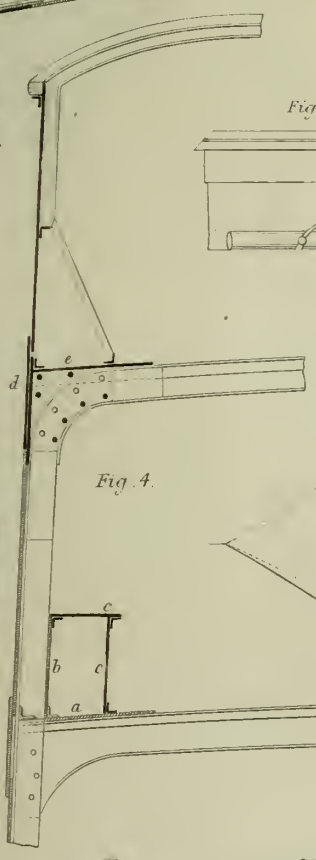


Fig. 3.

Fig. 4.



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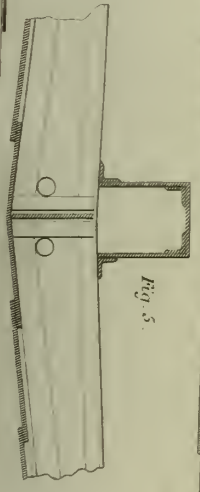


Fig. 6.

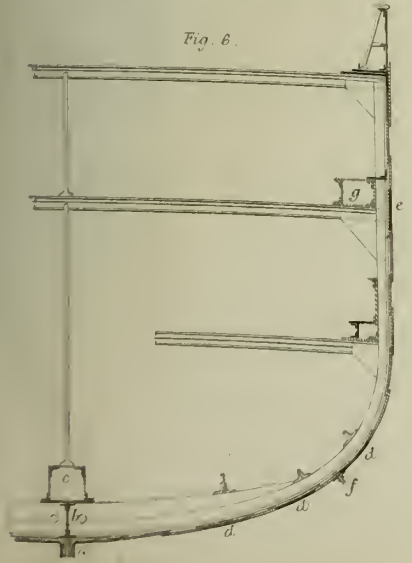


Fig. 7.

Fig 8.

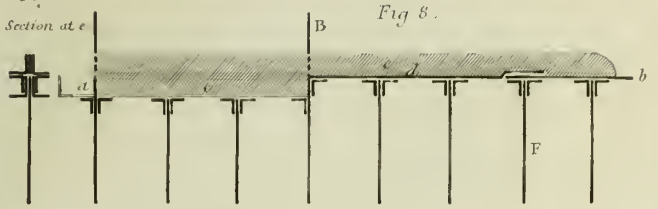
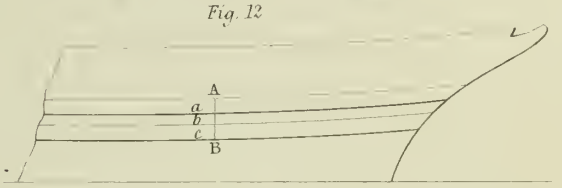


Fig 9

Fig 10

Fig. 11.

Fig. 12



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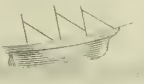

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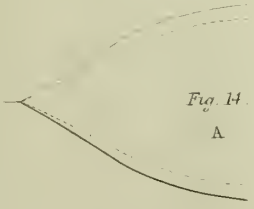


Fig. 15. Port Side

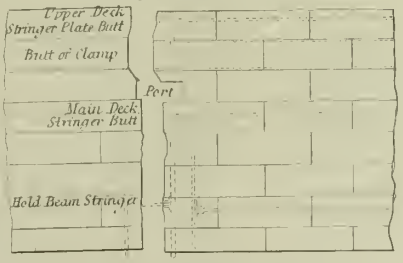


Fig. 16 Starboard Side

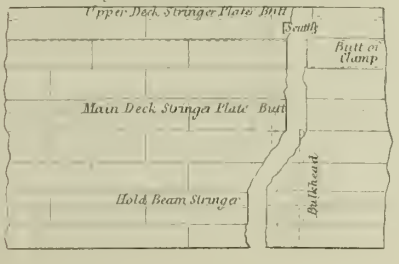


Fig. 17

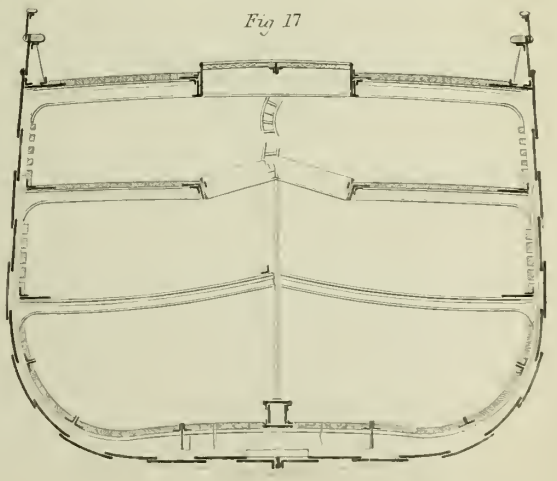


Fig. 18.

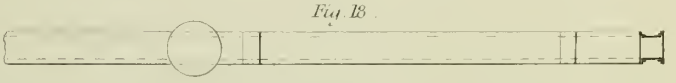
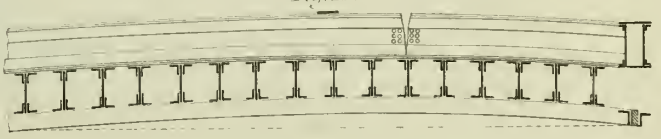


Fig. 19.



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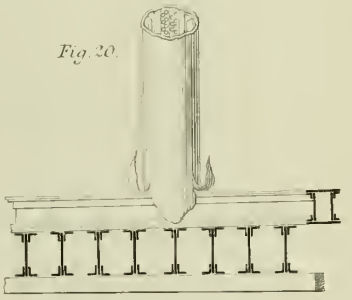

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Admiral Paris's Wave-tracer.

Scale 3/4 of actual size

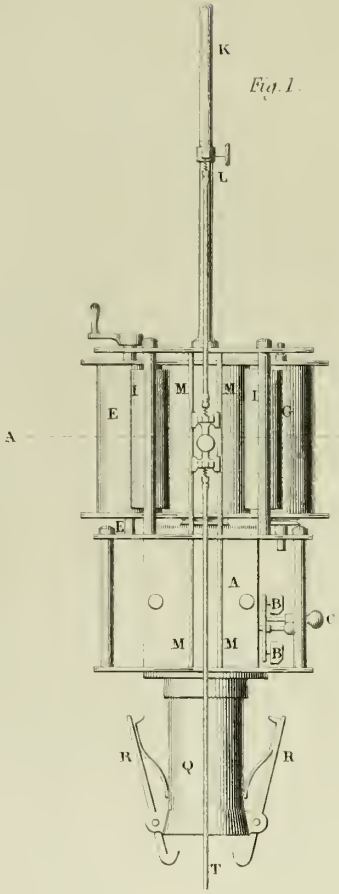


Fig. 1.

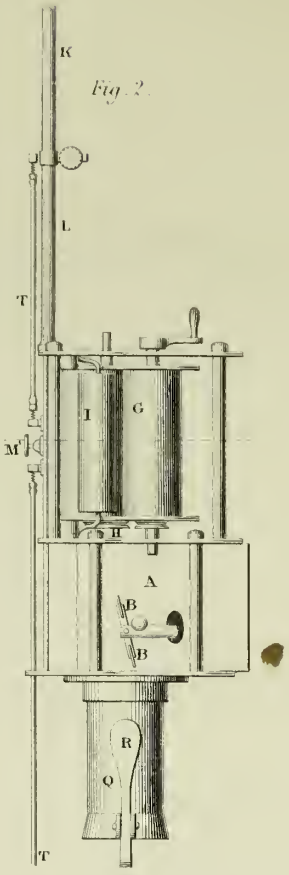
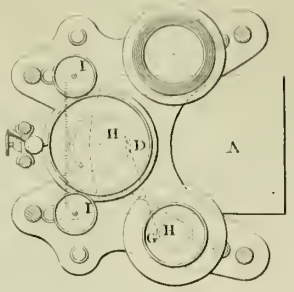


Fig. 2.

Section on line A B

Fig. 3



Tracing Machinery

Fig. 5.

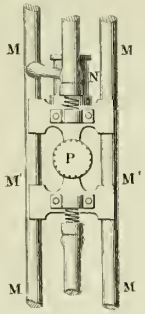


Fig. 6

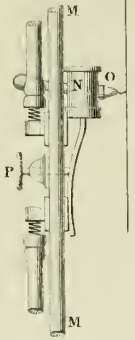


Fig. 7

General view 1/20 of actual size.

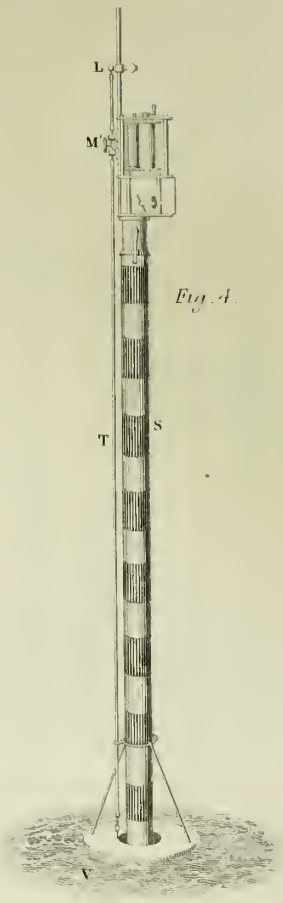


Fig. 4.

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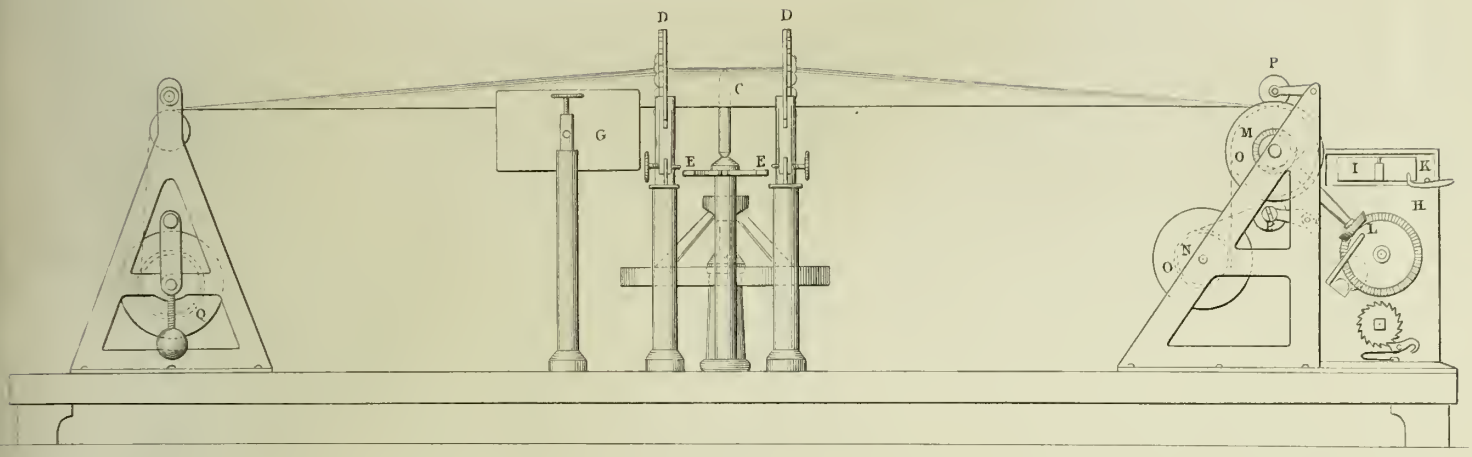
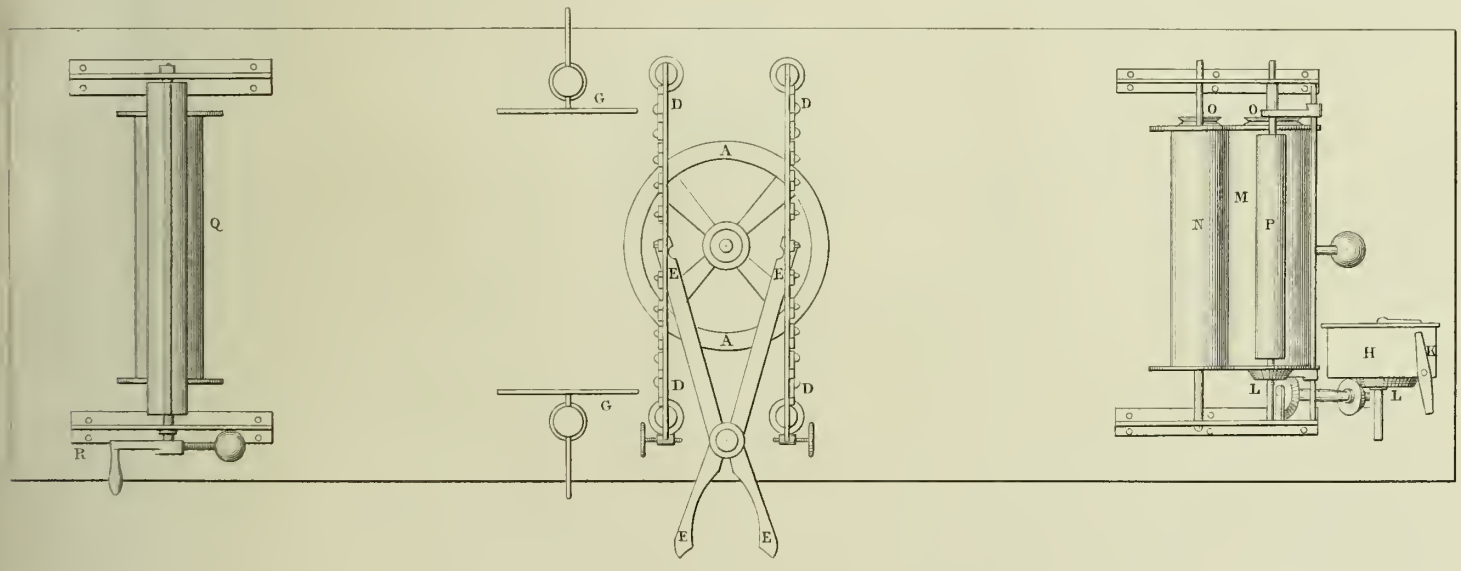
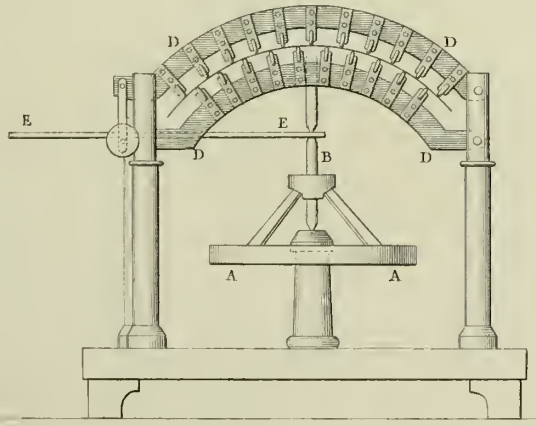
Admiral Paris's Roll-tracer.







Scale ⅓ of actual size

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Trans. I

ll-tracer.

rain. Remains of a heavy sea there had been in the nig

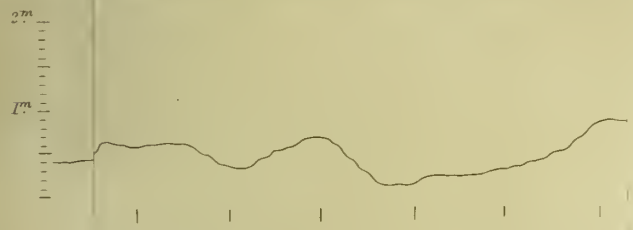


Fig. 3. Wave curve reduced to 1/5 of actual trace. Taken 25h
Sea

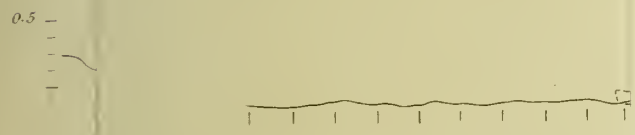


Fig. 5. Representation

Fig. 7. Representation

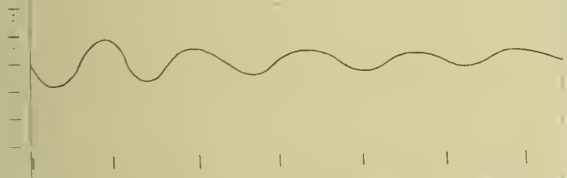


Fig. 9. Oscillation of the boat in calm water. Weights at

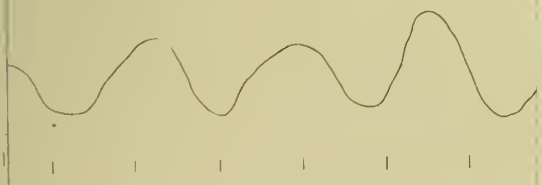


Fig. 11. Rolling. We

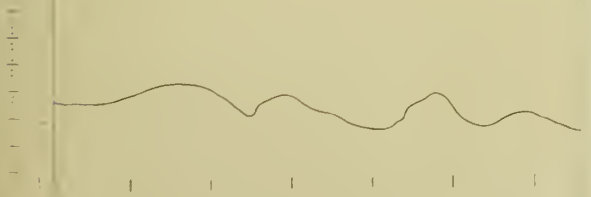


Fig. 13. Rolling. Weigh

ves, and degrees for the rolling.

To illustrate Admiral Dans's Paper on his Wave tracer and Roll tracer

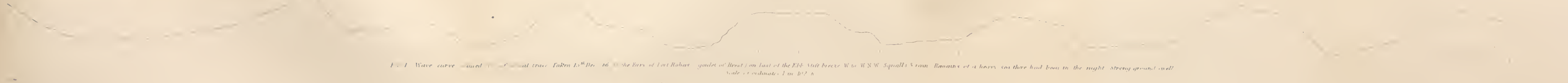


Fig 1. Wave curve reduced to [illegible] of actual trace. Taken 13th Dec. 66 in the Bays of Loch Robert (goulet of Brest) on East of the Ebb. Stiff breeze W to W.N.W. Squalls & rain. Remains of a heavy sea there had been in the night. Strong ground swell.
Scale of ordinates 1 in 103.8

Fig 2. Wave curve reduced to [illegible] of actual trace. Taken [illegible] at St Anne [illegible] in the Bay [illegible] in a high Fresh breeze from S.W. Heavy Sea [illegible] Scale of ordinates 1 in 81.6

Fig 3. Wave curve reduced to 1/16 of actual trace. Taken 25th June 1866 at the mouth of the Morbihan River. Light breeze from N.E. Squalls and Rain.
Scale of ordinates 1 in 71.6

Fig 4. Wave curve reduced to 1/16. Taken 7th Feby 66 in Brest roads. Light breeze variable and veering S.W. Flood tide with wind. Scale of ordinates 1 in 43.4

Fig 5. Representation on a scale of one in 1600 of the trace in Fig 4. Speed of Waves 4.5 metres per second

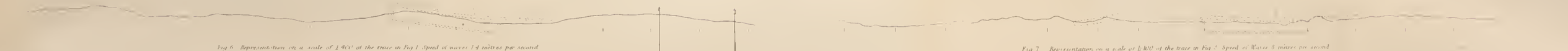


Fig 6. Representation on a scale of 1/400 of the trace in Fig 1. Speed of waves 14 metres per second

Fig 7. Representation on a scale of 1/400 of the trace in Fig 2. Speed of Waves 8 metres per second

Fig [illegible] Oscillation of the boat in calm weather. Weights on the thwarts unequal. Reduced 1/3

Fig 9. Oscillation of the boat in calm water. Weights at the bottom, amidships. (Reduced 1/3)

Fig 10. Rolling. Weights hung overboard. Reduced 1/3

Fig 11. Rolling Weights on the thwarts unequal. Most ship-like. Reduced 1/3)

Fig 12. Rolling Weights on the thwarts amidships. Reduced 1/3

Fig 13

Fig 13. Rolling. Weights on the bottom amidships. (Reduced 1/3)

N.B. The horizontal divisions give seconds, throughout. The vertical divisions give metres for the wave curves, and degrees for the rolling

To illustrate Mr. M. Scott's Paper on an improved method of constructing Composite Ships.

Fig. 1.

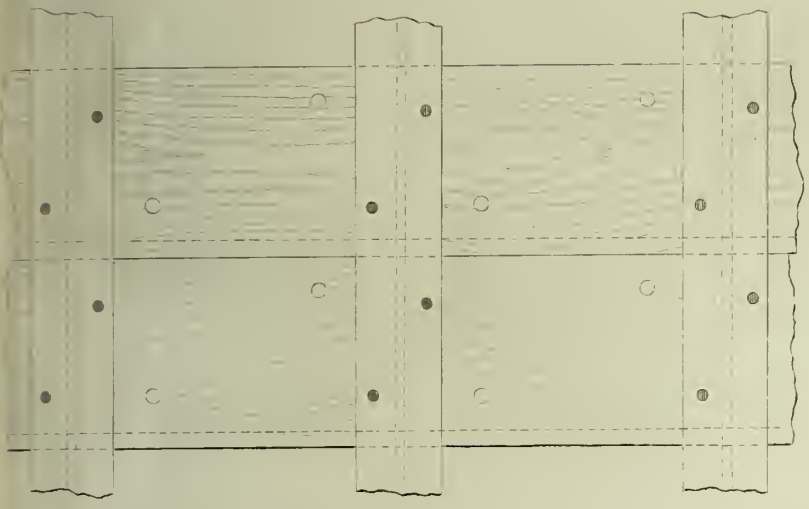


Fig. 5

Fig. 2

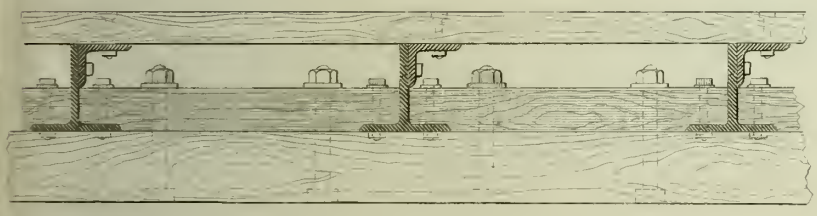


Fig. 6.

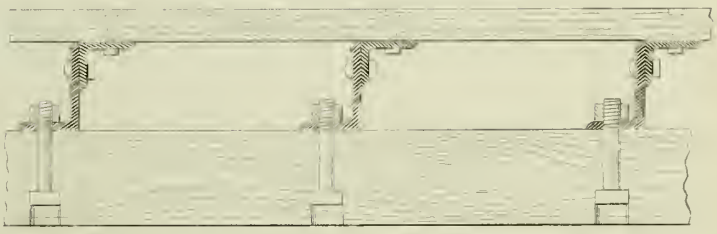


Fig. 3.

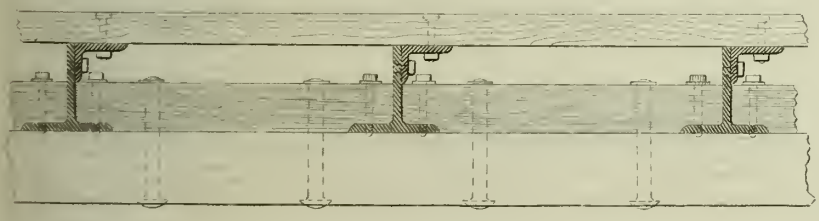


Fig. 7.

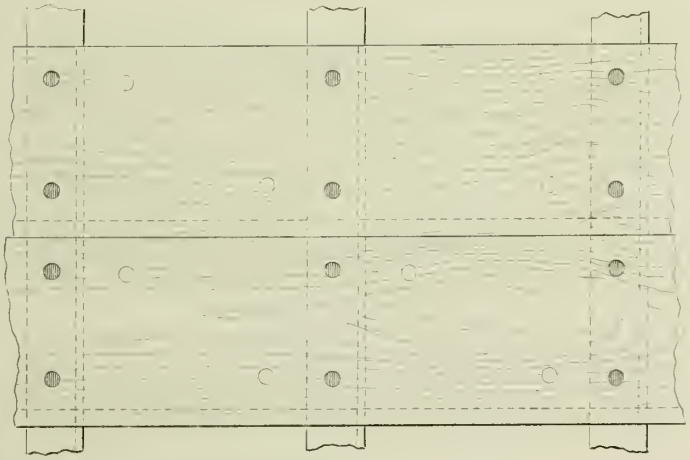


Fig. 4.

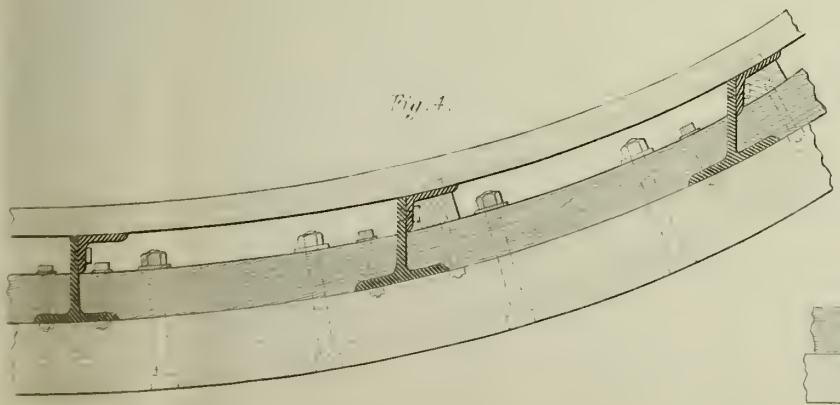
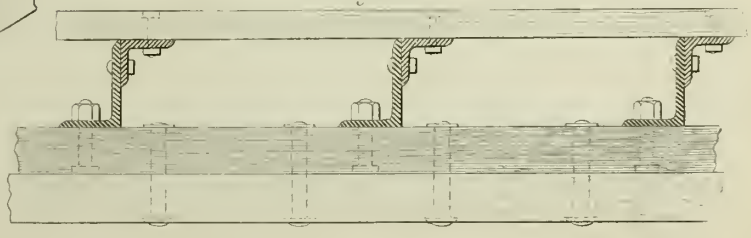


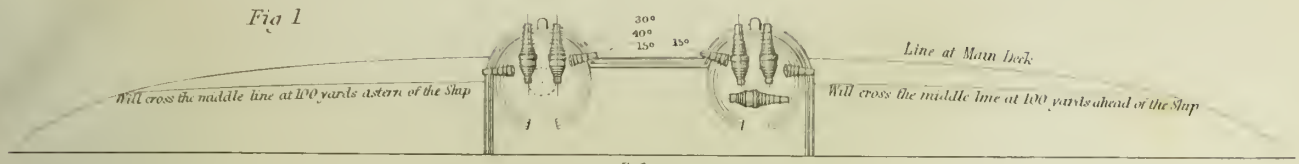
Fig. 8.



Engraved by J. W. Lee

To illustrate Mr Lancaster's Paper on the application of the "Caponière" system to Sea going Ships of War.

Fig 1


30°
40°
15°
15°
Line at Main Deck
Will cross the middle line at 100 yards astern of the Ship
Will cross the middle line at 100 yards ahead of the Ship

Plan

Fig 2.

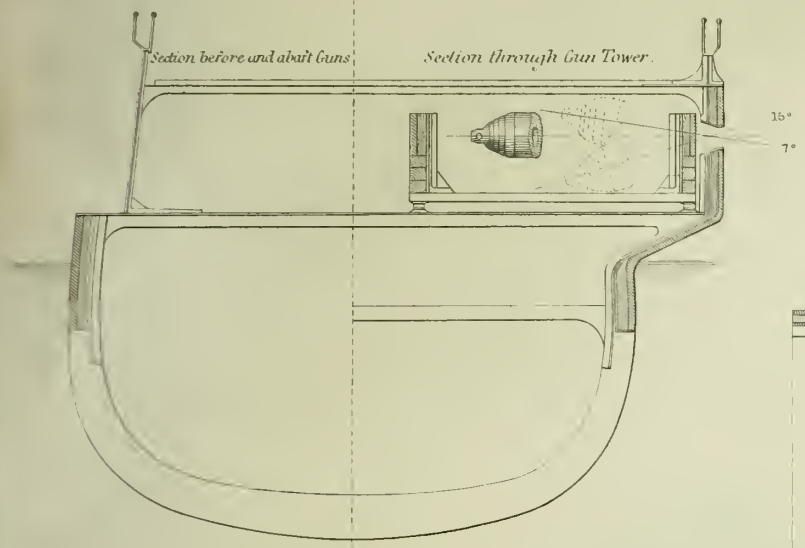


Fig 3. Elevation

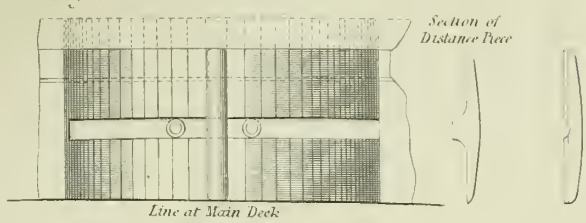
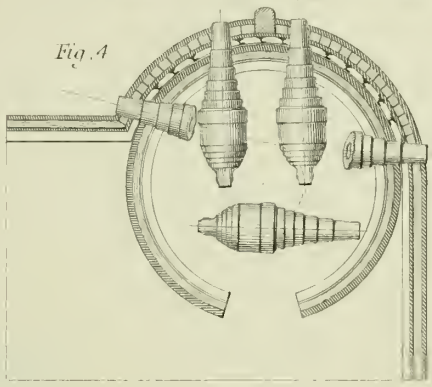


Fig 4



To illustrate Mr R.D. Napier's Paper on differential friction brakes.

Fig 5.

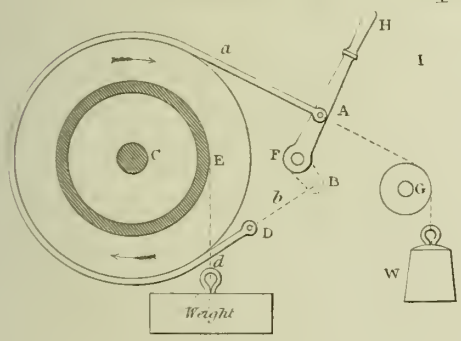
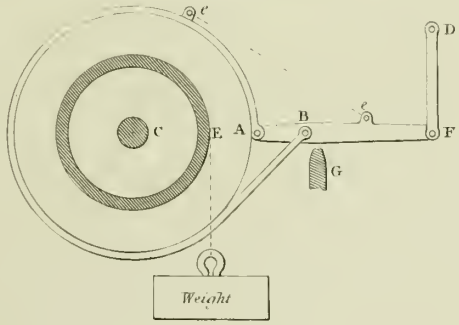


Fig 6.



To illustrate Mr Cunningham's Paper on working Ships' Yards.

Fig 7.

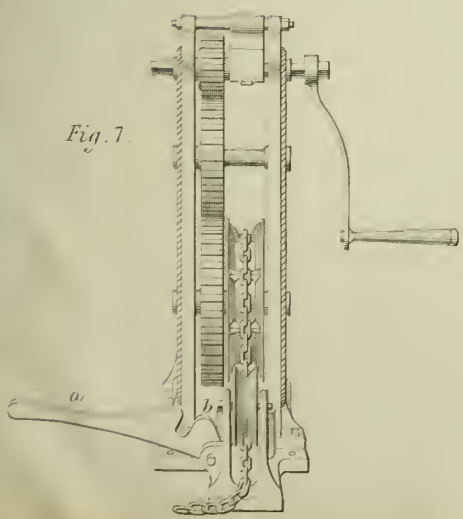
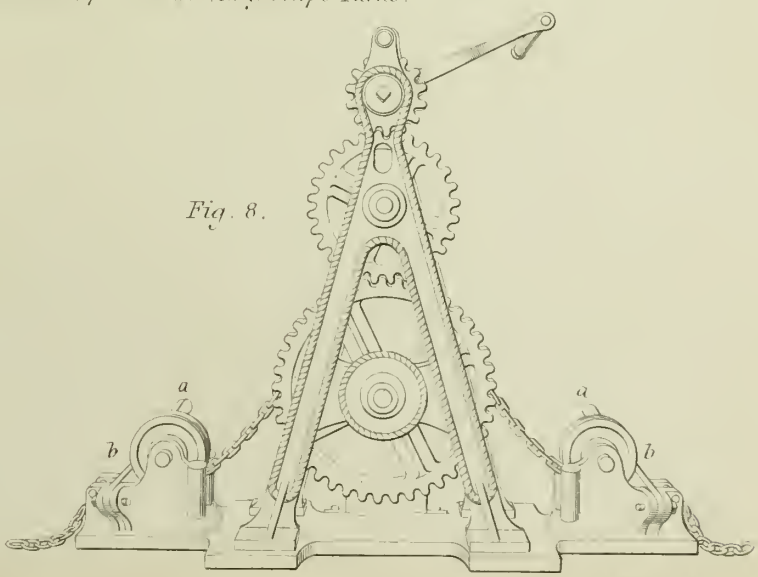


Fig 8.



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